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THE COLOR SENSITIVITY OF PHOTOGRAPHIC MATERIALS.*

BY

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IMMEDIATELY after the introduction of the daguerreotype process, its use for the photography of the spectrum showed that the maximum action was produced by the blue and violet rays and that the effect persisted beyond the visible spectrum into the region which was termed the "ultra-violet." In 1841, J. W. Draper enunciated the doctrine that "the chemical action produced by the rays of light depends upon the absorption of these rays by sensitive bodies, just as an increase of temperature is produced by the absorption of this with time." [1] This was suggested by a study of the sensitiveness of daguerreotype plates made with silver iodide and silver bromide and also of plates made by the bitumen process originally introduced by Niepce, in which it was shown that bitumen is sensitive to the entire visible spectrum, and the solar spectrum was recorded on bitumen up to the extreme red.

When silver iodide is produced by precipitation, it is of a clear yellow color with an absorption almost entirely in the blue, violet, and ultra-violet regions of the spectrum, so that its sensi-

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[1] J. W. DRAPER, *Phil. Mag.*, Sept., 1841.

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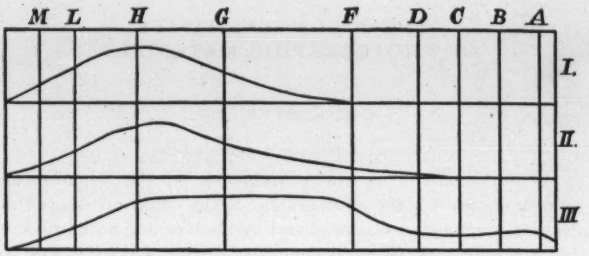
tivity is confined to these regions. As prepared upon a daguerreotype plate, however, it is possible to obtain a silver iodide of many varied colors according to the exposure of the silver to the iodine vapor, and the sensitiveness of the iodide so formed was found by Draper to depend upon its optical properties. These conclusions of Draper were confirmed later by Abney and Eder, who found that by ripening precipitated silver bromide, its visible absorption was changed and that at the same time its

FIG. 1.



Sensitiveness of silver chloride in collodion.

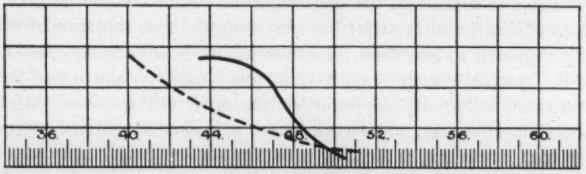
spectral sensitiveness was extended into the red and even the infra-red regions of the spectrum. Thus, in Fig. 1,[2] No. I represents the sensitiveness of the ordinary form of silver chloride in collodion, the film appearing red by transmitted light. No. II is the same chloride emulsified in gelatine, which appears gray by transmitted light. No. III is a special red-sensitive form of silver bromide emulsified by Abney in collodion.[3] This collodion emulsion was blue by transmitted light and was sensitive far into the infra-red region. It is stated by Abney to be "sensitive to very low radiations, such as the radiations proceeding from boiling mercury or even boiling water."

In Fig. 2 are shown approximate measurements of the absorption and sensitivity curves for silver bromide and for mixtures of silver bromide with silver iodide. When silver iodide is precipitated together with silver bromide, it has been shown by Wilsey[4] that the precipitated crystals have the structure of silver

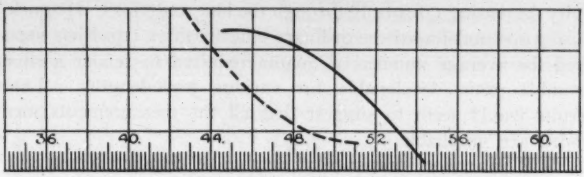
[2] From Meldola's "Chemistry of Photography."
[3] *Phot. Jour.*, 1881, **5**, p. 95.
[4] JOUR. FRANK. INST., Dec., 1925, p. 739.

bromide, the iodine entering into the cubic lattice. Such precipitates are very strongly colored, having a much deeper color than

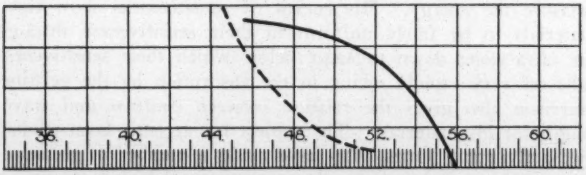
FIG. 2.



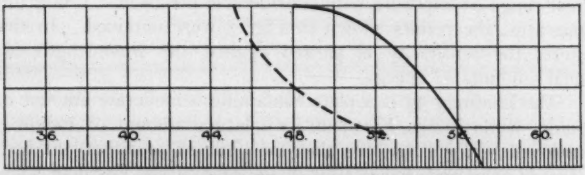
Pure silver bromide.



5 per cent. silver iodide, 95 per cent. silver bromide.



10 per cent. silver iodide, 90 per cent. silver bromide.



25 per cent. silver iodide, 75 per cent. silver bromide.

Absorption and sensitiveness curves of silver bromide containing silver iodide. Dotted line, absorption curve; solid line, sensitiveness curve.

pure iodide, and accompanying this color is a considerable extension of sensitivity into the green region of the spectrum.

Emulsified silver chloride is sensitive almost entirely to the

ultra-violet, having very little sensitiveness in the visible spectrum, this corresponding to the fact that it shows no visible color to the eye.

The distribution of the sensitiveness of ordinary photographic materials in the ultra-violet has only recently been measured with any approach to precision. Leimbach [5] made a systematic study of the spectral energy sensitivity of five emulsions and found the maximum sensitivity to occur in the spectrum at about λ450, Luckiesh, Holladay, and Taylor [6] have published sensitivity curves for four emulsions, indicating a maximum sensitivity near λ450. Otashiro [7] finds a maximum sensitivity at about λ465, the sensitivity decreasing uniformly through the blue and violet. Helmick [8] (using an emulsion of the ordinary blue-sensitive type) has measured the average number of quanta required to render a silver bromide grain developable for various wave-lengths. Later results would seem to suggest that all the measurements mentioned are unreliable.

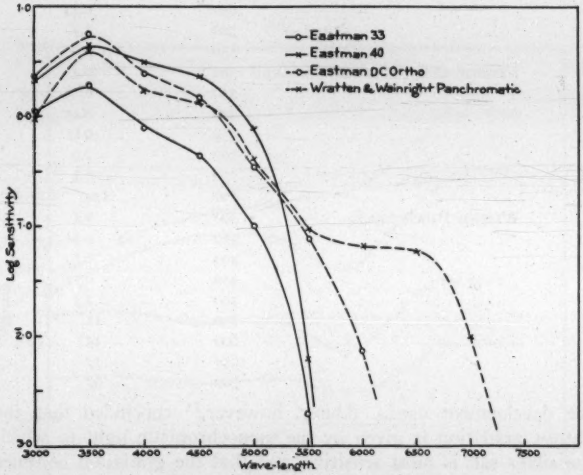
G. R. Harrison [9] measured a number of commercial materials using a mercury lamp as the source of light and a thermopile to measure the energy. His curves of sensitiveness show these materials to be fairly uniform in their sensitiveness through the ultra-violet down to λ240, below which their sensitiveness falls off very rapidly owing to the absorption by the gelatine. Harrison also gives the relation between contrast and wave-length for his materials. The subject has recently been studied by Sandvik and Jones, who have made a number of measurements using a monochromatic sensitometer adapted to give a great range of exposure with considerable precision. Using this apparatus, the results shown in Fig. 3 were obtained. In this figure, the sensitivity is plotted against the wave-length for equal amounts of energy.

The Eastman 33 is a plate containing a moderate amount of iodide, while in the Eastman 40 a larger amount of iodide is employed. It will be seen that the limit of sensitivity of both plates is λ550 and that it rises in the case of the Eastman 33 in

[5] *Zeit. Wiss. Phot.*, 7, 1909, p. 157.
[6] JOUR. FRANK. INST., 196, 1923, p. 353.
[7] *Bull. Kiryer. Tech. College*, Japan, No. 2, Aug., 1923.
[8] *Jour. Opt. Soc. Am.*, 6, 1922, p. 998.
[9] *Jour. Opt. Soc. Am.*, 9, 1925, p. 341.

the ultra-violet to λ350, while in the case of the Eastman 40, high sensitivity is already reached at λ480, and there is little increase beyond this. It is possible that the drop shown beyond λ350 is due to failure of the reciprocity law and that in accordance with the results obtained by Harrison, the sensitivity for equal energy really remains constant throughout the ultra-violet until the absorption of the gelatine becomes effective. Table I shows the energy in ergs per square centimetre required to produce

FIG. 3.



Wave-length sensitivity curves of plates.

a density of unity when developing to a γ of unity upon the materials in question.

In addition to measuring the sensitiveness, it is necessary to measure the variation of contrast with wave-lengths. The fact that the photographic contrast changes with wave-lengths appears to have been discovered nearly simultaneously by Abney and by Precht in 1899. In 1900, Chapman Jones made a careful and detailed study of the phenomenon and concluded that in general the contrast changes continuously from the ultra-violet to the red,[10] though to some extent the effect was found to be dependent upon

[10] *Phot. Jour.*, 1900, **24**, p. 279.

TABLE I.

Emulsion.	λ	Energy.
Eastman 33	300	0.90
	350	0.53
	400	1.3
	450	2.3
	500	10
	550	51
Eastman 40	300	0.47
	350	0.23
	400	0.33
	450	0.43
	500	1.3
	550	160
Eastman D C Ortho	300	0.43
	350	0.18
	400	0.41
	450	0.67
	500	2.9
	550	8.3
	600	134
Wratten Panchromatic	300	1.1
	350	0.24
	400	0.59
	450	0.74
	500	2.5
	550	11
	600	15
	650	17
	700	97

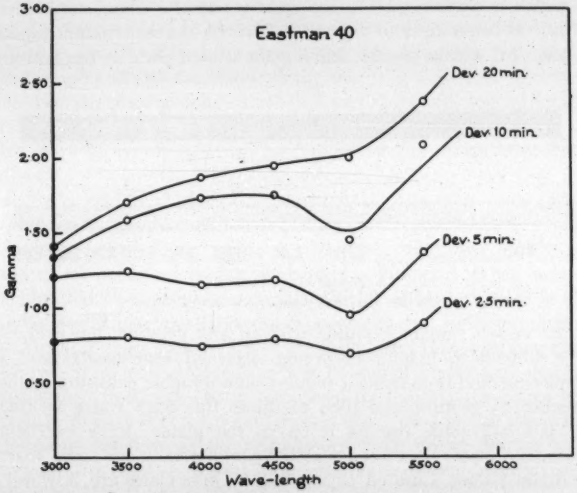
the development used. Abney, however,[11] concluded that the flattest gradation is given by the monochromatic light to which the silver salt is most sensitive, and that the gradation becomes steeper as the wave-length of light employed departs at either part in the spectrum from this point, the steepest gradation being given by the extreme red. Abney's result has not been confirmed by other workers, and it is probable that the variation of gradation with wave-length varies very much with the emulsion and to some extent also with the development; it seems impossible to generalize on the phenomenon since it is necessary to measure it for each individual emulsion.[12] Harrison found the variation of γ with wave-length to depend very much upon the emulsion, a process

[11] *Proc. Roy. Soc.*, 1901, **68**, p. 300.

[12] For a fuller discussion of the history of the subject, see Ross, "Physics of the Developed Photographic Image," p. 82, *ff*.

plate showing a very great variation throughout the ultra-violet, while plates of higher sensitivity showed a small variation. The results obtained by Sandvik and Jones are shown in Fig. 4, where it will be noticed that there is a variation for all times of development, but that the shape of the γ-wave-length curve depends distinctly upon the time of development. Complete explanation has yet to be given of the shape of this curve and especially of the curious drop in contrast at λ500 which has been noted by previous workers. It is probable that the shape of the curve is strongly

FIG. 4.



Curves showing relation between contrast and wave-length.

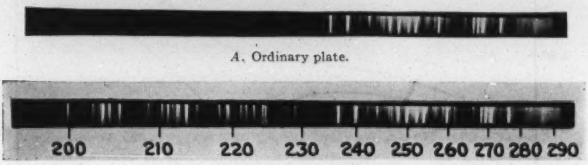
associated with the absorption of the light as it penetrates the emulsion, and that an explanation dependent upon this penetration and possibly on the spectral sensitivity of the different sizes of grains of which the emulsion is composed may eventually prove satisfactory.

When the ultra-violet region of the spectrum below λ250 is photographed, the absorption by the gelatine becomes important, gelatine having a strong absorption for ultra-violet light below λ280 and absorbing practically all radiation below λ200 even in

very thin layers. Fig. 5 (*A*) shows the way in which the ultra-violet spectrum falls off in intensity when photographed on an ordinary plate owing to absorption of the gelatine.

Schumann, when studying the extreme ultra-violet spectrum, worked out a method of making plates which would be sensitive to the very short waves either entirely free from gelatine or containing only a small trace of gelatine to bind the silver bromide together.[13] Schumann made his plates by precipitating silver bromide from weak solutions containing an excess of potassium bromide, the suspension being then placed in a vessel at the bottom of which is a clean glass plate upon which the silver salt settles down. When a layer of the salt is formed, the supernatant liquid is taken off with a pipette, leaving the coated plate at the bottom

FIG. 5.



A. Ordinary plate.

B. Treated with mineral oil.

Ultra-violet spectra on ordinary and treated plates.

of the vessel. Silver bromide without any gelatine, however, is very difficult to handle, becoming detached very easily, and a simpler method is to make a regular photographic emulsion in the presence of gelatine and then to dilute this with water so that the salt will settle out of it on to the plate. Very excellent Schumann plates have been supplied commercially for some years by Adam Hilger, Limited, of London. These plates are, however, very difficult to make and expensive when bought.

Duclaux and Jeantet[14] describe two other means of photographing the extreme violet, one by treating an ordinary plate with sulphuric acid so as to dissolve the gelatine, and the second by bathing the plate with fluorescent materials, such as mineral oils, these materials transforming the short waves into longer ones which can penetrate the gelatine. In the last few years, this method has been applied generally with success, Lyman having

[13] For a description of Schumann's method, see Baly, "Spectroscopy," p. 359.

[14] *Jour. de Phys. et le Rad.*, **2**, 1921, p. 156.

used plates treated in this way in the extreme ultra-violet down to 58mμ.[15]

Various oils give results which differ somewhat in different workers' hands, and this aspect of the subject, together with the use of a fluorescent oil for photometry, has been investigated by G. R. Harrison.[16] A satisfactory procedure is to coat the plate with a thin layer of a clear paraffin oil such as "Nujol." After exposure, the oil is removed in a bath of acetone, care being taken to allow sufficient time for this. If much work is being done, it is worth while to experiment on different oils, since Harrison shows that they vary very much in their properties owing to difference in fluorescence and in absorption, and for different wave-lengths there is considerable difference in the oil giving the best results. Fig. 5 (*B*) shows the effect of the oil.

For the photography of the red and infra-red, special modifications of the silver salts were used by Abney, while Draper did his work by an effect which he discovered and which is probably allied to the so-called *Herschel* effect. Draper found that if a daguerreotype plate during exposure to the spectrum was exposed also to faint white light, the extreme red was recorded reversed, and he ascribed this to the reversal by the red of the spectrum of the effect produced by the blue light. Herschel[17] had already found that photographic materials which had been exposed to blue light would give positives on exposure to red light by reversal of the first exposure. Waterhouse found that this reversing effect of red light was obtained on wet collodion plates and that the reversing effect was greatly increased by staining the plates with certain dyes. When Luppo-Cramer discovered the desensitizing action of the dyes of the azine group,[18] he found that in plates treated with these dyes a latent image was destroyed by exposure to the dark-room light. Millochau[19] photographed infra-red spectra by the use of plates treated with an alcoholic solution of Malachite Green, obtaining reversal effects in the solar spectrum to λ932, and Terenin,[20] with a number of dyes of the azine and phenyl methane

[15] *Nature*, 1923, **112**, p. 202.

[16] *Jour. Opt. Soc. Am.*, 1925, **11**, p. 113.

[17] *Phil. Trans.*, Part I, 1840.

[18] "Der Photographe," 1920, p. 368, and "Negativ-Entwicklung bei Hellem Lichte," 1922.

[19] *Compt. Rend.*, 1906, **143**, p. 108.

[20] *Zeit. f. Phys.*, 1924, **23**, p. 294.

groups, was able to photograph the mercury line at 1128. A discussion of the whole subject is contained in a paper by Carroll,[21] who studied a number of dyes and inorganic materials for their tendency to cause reversed images on the exposure of preëxposed plates to the spectrum and found that the long wave-length limit of this process was approximately the same as that shown by plates sensitized by dicyanine. Carroll thinks that the action is connected with the oxidation theory of desensitization. "The dyes in the dark or in visible illumination have an oxidization potential sufficient to prevent formation of new latent image. On activation by light of their characteristic frequency, their potential is raised sufficiently to cause destruction of the latent image already existing." A study of a very considerable number of inorganic materials and dyes showed that two groups of dyes—the azines and triphenyl methanes—are effective, perhaps the best all-round results being obtained with Malachite Green. The wave-length of the light by which the preliminary exposure is given is unimportant, but the amount of the exposure should be chosen with some care, the best results being by such an exposure that a density of unity would be obtained upon development. The plate is bathed before exposure in the spectrograph in a 1 : 1000 solution of Malachite Green made acid by the addition of 2 per cent. nitric, sulphuric, or hydrochloric acid. With long exposures it is not difficult to register the mercury line at λ1014 on plates so prepared, and they may be considered about as sensitive for infra-red spectroscopy as Dicyanine-bathed plates.

In 1873 H. W. Vogel noticed that some commercial collodion emulsion plates of which the film contained a small amount of yellow dye to diminish halation showed a sensitiveness towards the solar spectrum differing from those of the usual plates of the same kind. This effect was traced by Vogel to the dye which had been added to the emulsion and led to the discovery that when dyes were put in a silver bromide collodion emulsion they increased the sensitiveness according to their absorption. The first dye used by Vogel was Corallin, which has an absorption band in the yellow-green and was found to sensitize for that region of the spectrum. This discovery received little credence at first because Draper's clear enunciation of the relation between absorption and sensitiveness had been largely ignored, but continuing his work Vogel found a

[21] *Jour. Phys. Chem.*, 1925, p. 693.

large number of dyes which sensitized his plates in accordance with their absorption. One of these, which was afterwards to become most important, was Cyanine, a dye produced by the condensation of Lepidine with Quinoline.

Waterhouse found that Eosin sensitized collodion emulsion, and shortly afterwards Clayton and Tailfer found that Eosin would sensitize gelatine emulsions and obtained a patent for its use in England and France, plates sensitized with Eosin being placed on the market under the name of *Isochromatic* plates. These isochromatic plates prepared under the Clayton-Tailfer patent were made by several of the early manufacturers of dry plates in different parts of the world and for many years were the only color-sensitive plates used generally by photographers.

In 1884, Vogel found that Quinoline Red was a satisfactory sensitizer for the orange, yellow, and greenish-yellow and sensitized plates with a mixture of Quinoline Red and Cyanine, these being termed *Azaline* plates. He found also that Eosin sensitized emulsions most powerfully when used in the form of its silver salt dissolved in ammonia, and Eosin-silver plates were placed on the market in Germany. In the same year Eder discovered that Erythrosin, the iodine analogue of Eosin, was a still better sensitizer and that Erythrosin used as the silver salt was the most powerful sensitizer available for the green region of the spectrum. At the present time Erythrosin is used almost exclusively for the preparation of the isochromatic and orthochromatic plates on the market and gives a very characteristic spectrum with a maximum at $\lambda 565$ and a sharp minimum at $\lambda 500$ between the blue region of sensitiveness and the band in the yellow-green characteristic of the dye (Fig. 6).

In 1904 new groups of sensitizing dyes were discovered which were so much more powerful than those known previously that they changed the whole position of the color sensitizing of photographic materials. Previous to that period, the dyes used for materials employed in general photography, including color photography, were limited to Eosin, Erythrosin, Quinoline Red, and Cyanine, but a considerable number of other dyes were used for the photography of the spectrum. Thus, Higgs, in his exhaustive study of the solar spectrum, used for the red end Alizarin Blue in the form of the bisulphite compound, this being prepared by the treatment of Alizarin Blue paste with sodium

bisulphide solution.[22] Nigrosine was also used either alone or in combination with Alizarin Blue.

Eder and Valenta tested a great number of dyes and recommended certain of them for the photography of the red end of the solar spectrum, these including Diazo Black BHN, several of the wool blacks, and Columbia Green, with which the furthest extension into the red end of the solar spectrum shown in Eder and Valenta's "Beiträge" was obtained. All these dyes are, however, now only of historical interest. An interesting dye still having some value is Acridine Orange NO, which extends the sensitiveness of the ordinary emulsion to λ580. This is the best sensitizer available for the region between λ500 and λ540.

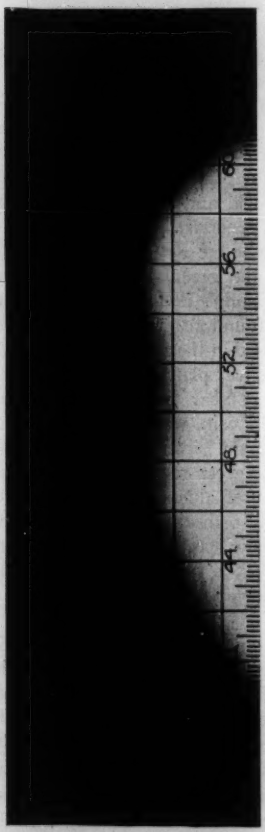


FIG. 6. Wedge spectrum of Erythrosin-sensitized emulsion.

The new period referred to above in the development of the sensitivity of photographic materials arose with the discovery of the sensitizing power of Ethyl Red by Miethe and Traube in 1902. The dye termed by them *Ethyl Red* was an analogue of Cyanine Blue discovered by Spalteholtz in 1883 and prepared by the condensation of quinaldine ethiodide with quinoline ethiodide. Miethe and Traube found that this material was superior to Cyanine as a sensitizer and that the emulsions made with it were

[22] Baly, "Spectroscopy," p. 353 (1905 edition).

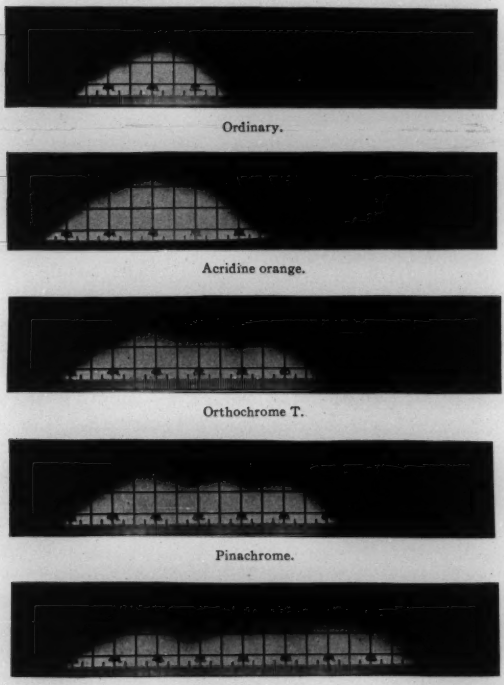
not subject to the trouble of fogging and bad keeping which was characteristic of those made with Cyanine Blue. At the time this discovery was made, E. König was working at the Hoechst Dye Works on photographic sensitizing, and from his knowledge of organic chemistry produced a whole series of the isocyanine dyes in rapid succession, the dyes differing from each other in the groups which were inserted in the nucleus. Among those of the greatest interest should be mentioned Orthochrome T, Pinaverdol, and Pinachrome, all of which were placed on the market before 1904 by the Hoechst Dye Works. These dyes sensitized as far into the red as λ650, but they are essentially sensitizers for the green and orange; a true sensitizer for the red itself was not discovered until 1906, when Homolka, working at the Hoechst Dye Works, discovered Pinacyanol. The constitution of Pinacyanol was for long a matter of doubt, but its constitution is now clear from its mode of preparation. Homolka originally made it by adding formaldehyde to the alkaline condensation of quinaldine ethiodide with quinoline ethiodide, but it is now known that the quinoline forms no part of the final product and that the reaction is really determined by the formaldehyde, which supplies an extra CH group.

Dyes of the type of Pinacyanol are now known as the *carbocyanines*. A few substituted carbocyanines have been introduced, one of the most valuable being naphthacyanole, prepared by the use of beta-naphthaquinaldine ethiodide, which has a naphthalene group included in its nucleus; by means of this dye the sensitiveness of the spectrum can be extended to about λ750.

Shortly after the introduction of Pinacyanol, the Hoechst Dye Works introduced another dye which they termed *Dicyanine*, and which they prepared by the condensation of 2.4-dimethylquinoline ethiodide upon itself with simultaneous oxidation. The sensitizing power of Dicyanine will be discussed later, but it may be said that it in no way took the place of Pinacyanol, although for work in the extreme infra-red it has been a most valuable dye from the time of its introduction to the present day. The progress of this period, which was the great period in the field of sensitizing dyes, is shown in Fig. 7, in which are illustrated the spectra of an ordinary emulsion and of the same emulsion sensitized with Acridine Orange, Erythrosin, Orthochrome T, Pina-

chrome, and Pinacyanol. It will be noted how the spectrum expanded towards the red until with Pinacyanol the whole visible spectrum was covered, and by the use of combinations of Pinacyanol and such green sensitizers as Orthochrome, Pinaver-

FIG. 7.



Wedge spectra of plates treated with various sensitizers.

dol, or Pinachrome, panchromatic materials could be made fully sensitive to the whole of the visible spectrum.

The spectra shown in Fig. 7 are made on a special spectrograph for testing photographic sensitivity. This is a small diffrac-

tion grating instrument of the type shown in Fig. 8. The plate holder is fitted with a scale of wave-lengths which are impressed upon the spectrum when it is photographed, the second order overlapping ultra-violet being cut out by dying the gelatine of the scale at one end. Such a spectrum is normal, and it is easy to obtain uniform intensity throughout by proper arrangement of the optical system. It is convenient to have an automatic indication of the variation of sensitiveness throughout the spectrum, and this can be obtained by graduating the intensity of the spectrum vertically. The best way of doing this is undoubtedly by

FIG. 8.

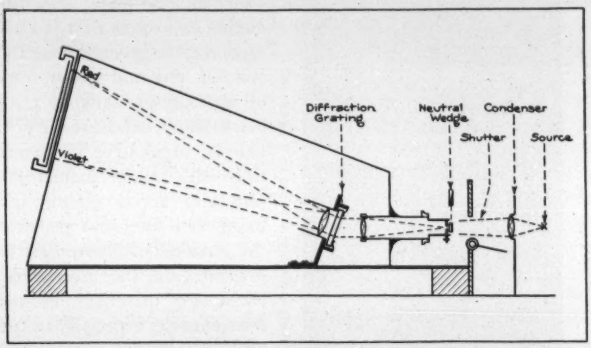


Diagram of wedge spectrograph.

the use of a rotating sector, but such sectors of small size are very difficult to make and to keep clean enough in use, since they are likely to show marks of all kinds from the accumulation of dust at the small end, and the more convenient and practical method is the use of a wedge of neutral glass at the slit, the only objection being that such a wedge shows a selective absorption in the ultra-violet and violet, and consequently the indications of the spectra cannot be trusted below about λ460.

The extension of color sensitivity as a result of the introduction of the new dyes produced at the Hoechst Dye Works was, of course, of the greatest importance in practical photography, and the panchromatic materials made by the use of the new sensitizing dyes were rapidly adopted very widely for commercial photog-

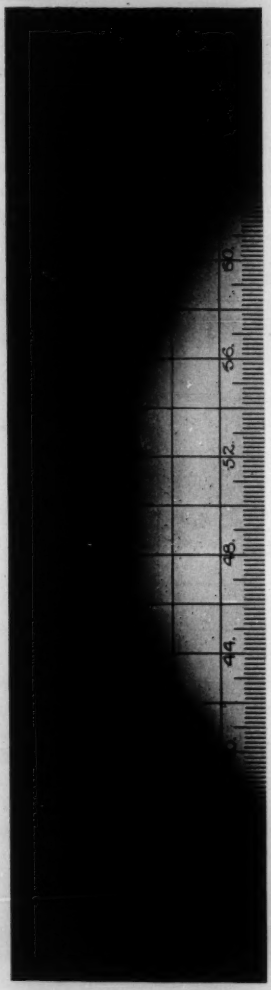


FIG. 9.

Wedge spectrum obtained with Pinaflavol.

raphy and to some extent for pictorial photography. They were also of the utmost importance in connection with color photography, and the modern methods of color photography depend essentially upon the possibility of obtaining materials of high sensitiveness throughout the visible spectrum. Modern panchromatic plates and films enable exposures of 1/50 of a second to be given through the tricolor red and green filters at apertures as low as f/4.5. Such short exposures are, of course, imperative in connection with color cinematography and aerial photography using red filters to penetrate the atmospheric haze. At the present time the use of panchromatic materials is very considerable, especially in connection with the negative material used for making motion pictures, a growing proportion of motion picture negatives being made upon panchromatic film.

During the Great War vast amounts of panchromatic material were used for aerial photography, the British Air Force especially relying almost entirely upon panchromatic plates for their work, and this caused a great development of activity in England, France,

and the United States in connection with the preparation of color sensitizers, especially as these could no longer be obtained from the German dye-makers who had originally discovered them.

In England, Sir William Pope and his colleagues prepared a dye of the isocyanine group which was marketed under the name of *Sensitol Green*, and another identical with Pinacyanol, which was termed *Sensitol Red*. Some other experimental dyes were prepared, notably *Sensitol Violet*, which, however, have found little application. In 1919 a useful dye was added to those supplied by the Hoechst Dye Works under the name *Pinaflavol*, this sensitizing through the green with a maximum at λ540, as shown in Fig. 9. This dye appears to be a homologue of a dye described by Mills and Pope,[23] which was prepared by the condensation of paradimethylaminobenzaldehyde with alpha-picoline methiodide. Pinaflavol is probably the ethiodide analogue.

In France a number of dyes were introduced by Lumière and Barbier.[24] Two of these, Cyanine A and Cyanine B, were of the isocyanine type, formed by condensing dimethyl-amino-quinoline with tolu-quinaldine or dimethyl-amino-quinaldine, respectively. A third, Pantachrome, which has been applied rather extensively as a sensitizer, is somewhat analogous to the dyes described above, being derived from dimethyl-amino-quinaldine ethiodide with dimethyl-amino-benzaldehyde. This dye sensitizes strongly up to about λ630 with a sensitivity extending to λ680.

In the United States, the isocyanines and Pinacyanol were prepared by several workers, publications on the subject being issued by the Bureau of Chemistry.[25]

Recent work in the United States has led to important extensions in the field of sensitizers for the extreme and infra-red. As will be seen from Fig. 10, the maximum of Dicyanine is at λ710, but the sensitizing action fades off very slowly, and Meggers, at the Bureau of Standards, and McLennan, in Toronto, have used it for spectroscopic work up to λ1000 with excellent results. Dicyanine is, however, a very unsatisfactory dye in use. It does not keep well, and the conditions for best results in sensitizing are rather obscure, so that the sensitive materials have to be made by bathing in solutions of the dye containing alcohol and ammonia,

[23] *Jour. Chem. Soc.*, 1922, **121**, p. 946.

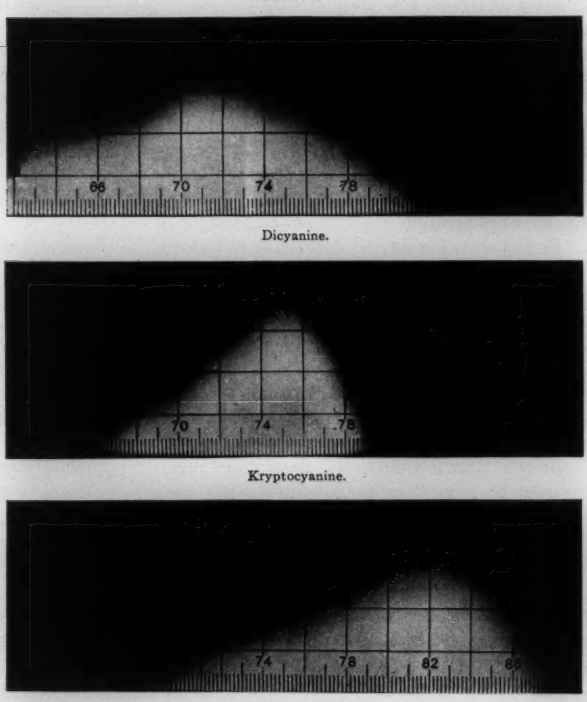
[24] *Bull. Soc. Franc.*, 1920, 7 (3), p. 182. For preparation of dye, see H. Barbier, *Bull. Soc. Chim.*, 1920, **27**, p. 427.

[25] *Jour. Ind. and Eng. Chem.*, 1919, **11**, p. 460.

and not infrequently many failures are encountered in their preparation. Only a few workers, indeed, have obtained the very best results by the use of Dicyanine.

In 1919 Adams and Haller, working at the Bureau of Chemis-

FIG. 10.



Dicyanine.

Kryptocyanine.

Neocyanine.

Wedge spectra of plates sensitized for the infra-red.

try, discovered a new dye formed by the condensation of lepidine in the presence of formaldehyde which they termed *Kryptocyanine*, and this dye has a very strong sensitizing band between λ700 and λ800 with its maximum at λ770 (Fig. 10). Kryptocyanine

sensitizes quite differently from Dicyanine. It is stable and can be added to the emulsion with excellent results, so that it is possible to produce ready sensitized materials without difficulty. It has an extraordinarily high sensitizing power, only one part in half a million of the dye being required—about a tenth of that used for Pinacyanol—but this cannot be utilized to attain stronger sensitizing, because if much more of the dye is added, it produces fog.

Unfortunately, Kryptocyanine, while it sensitizes very powerfully to λ800, has very little sensitizing power beyond that, so that when we reach λ900, its sensitizing power is considerably inferior to that of Dicyanine, and for spectroscopic purposes it did not therefore take the place of the latter dye.

In 1925, H. T. Clarke, while preparing Kryptocyanine, noticed that another type of less solubility was formed during the reaction. This was tested as a sensitizer by Schoen, Briggs, and Dundon, who found that it sensitized with a maximum at about λ820, giving the spectrum to λ900 with quite short exposure, and that when hypersensitized with ammonia, it became very easy to photograph λ1000 by means of it. This dye, which was termed *Neocyanine*, has the satisfactory practical properties of Kryptocyanine, though it has much weaker sensitizing power and therefore requires long exposures. It keeps well and can be used in emulsions without difficulty and is characterized especially by its powerful extension into the infra-red when hypersensitized.

The λ1014 line of mercury is very well known, originally discovered by means of the thermopile, and frequently photographed by McLennan and others on Dicyanine-bathed plates with long exposures. With hypersensitized Neocyanine plates this line can be photographed with less than an hour's exposure, and with exposures of about ten hours λ1129 has been reached.

At this point it will be convenient to sum up the progress in spectral sensitivity which has been made up to date. In Fig. 11 is seen a scale of wave-lengths from λ100 to λ1000, stretching from the boundary between the Schumann and Lyman regions to the limit of our photographic methods at the present time. The region from λ400 to λ700 is, of course, the visible spectrum. Before any sensitizers were known and before the use of quartz in spectroscopes was common, the photographic region may be taken as being from λ320, where glass absorbs, to approximately

λ500. If we consider that we have available quartz spectrographs and the sensitizers which were discovered by Vogel and Eder, the photographic spectrum stretches from λ200 to λ600, and while it is longer than the visible spectrum, it has not entirely overlapped it. The discovery of the isocyanines and Pinacyanol extended this spectrum to about λ730, which was the limit of the easily photographed spectrum until 1919, although by means of Dicyanine it had been extended with long exposures to about λ900. The discovery of Kryptocyanine by Adams and Haller extended the easily photographed spectrum to λ800, and Meggers and McLennan used Dicyanine up to λ1000. The discovery of Neocyanine in 1925

FIG. 11.

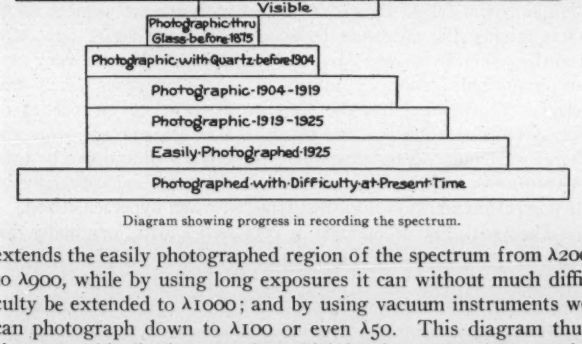


Diagram showing progress in recording the spectrum.

extends the easily photographed region of the spectrum from λ200 to λ900, while by using long exposures it can without much difficulty be extended to λ1000; and by using vacuum instruments we can photograph down to λ100 or even λ50. This diagram thus shows graphically the extension which has been achieved up to the present in the spectral region available for photographic use.

Soon after the discovery of Pinacyanol, R. W. Wood became interested in the photography of various objects by means of extreme red or infra-red light. He used for this purpose a filter cutting at about λ710, giving long exposures upon Pinacyanol-sensitized plates, and the results he obtained were sufficiently remarkable to attract a good deal of attention. The blue sky reflects very little light at such wave-lengths, and consequently it is almost black in the photographs. Chlorophyll, on the other

hand, has no absorption for the extreme red and, indeed, fluoresces at that point, absorbing orange light and emitting light of a wave-length around λ700, so that bright chlorophyll, such as that occurring in grass and trees, photographs as the highest (Fig. 12) lights of the landscape. The introduction of Kryptocyanine very greatly diminished the exposure necessary for these extreme red photographs, and J. A. Ball [26] applied the dye to the making

FIG. 12.

Photograph taken by infra-red rays.

of what are generally termed "night photographs" on motion picture film.

Night photographs are distinguished, of course, by the intense local lighting and by the blackness of the sky. They may be intended to represent moonlight or artificial light at night. Hitherto in motion picture work they have usually been taken at night, using very large batteries of lamps for illumination, and they are consequently very expensive to take. In the case of one scene which lasted only half a minute on the screen when finally used as part of the picture, it cost no less than $3000 to hire the

[26] *Trans. Soc. Motion Pict. Engs.*, 1925, **22**, p. 21.

FIG. 13.

Red-sensitive. Ordinary.

Yosemite Valley photographed from Mount Hamilton on extreme red-sensitive and ordinary plates.

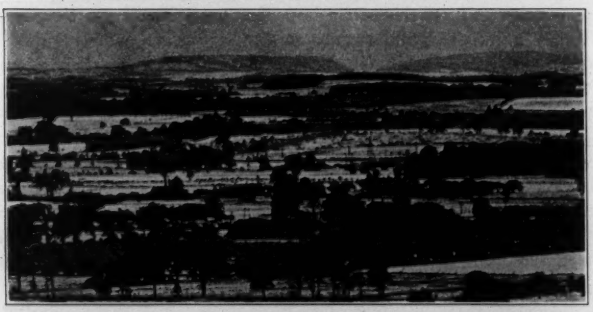
necessary electric equipment. By the use of Kryptocyanine film and a suitable filter, photographs which look as if they were taken by night can be exposed by sunlight with no additional cost in the photography, the photographs being taken at normal speed with an aperture of f/2 or, with hypersensitized film, of even f/3.5.

In addition to these bizarre effects, however, photography by long wave-lengths has the great advantage of giving a very high penetration through haze. Fig. 13 shows pictures taken by Prof. W. H. Wright, of Lick Observatory, from the top of Mount Hamilton. The Yosemite Valley is in the extreme distance, and in the valley between, thirteen miles from Mount Hamilton, is the town of San Juan. It will be seen in the photographs taken on an ordinary plate that no trace of San Juan is visible nor can anything, of course, be seen of the Yosemite Valley. Only the boundary hills can be seen against the sky. In the Kryptocyanine plate with a filter, the whole is perfectly clear and the Yosemite Valley a hundred and twenty miles away can be distinguished quite clearly. Working in the less clear atmosphere of the east, we have compared Neocyanine with Kryptocyanine for this purpose, photographing at about twenty miles distance with a long-focus lens. We took three photographs: One with an average wave-length of λ650 on a panchromatic plate with a red filter; one on Kryptocyanine with a filter; and one on Neocyanine with a special liquid filter giving a wave-length of λ875. The greater penetration of the Kryptocyanine than the panchromatic plate is well seen, but the Neocyanine plate is seen to give even greater penetration (Fig. 14).

Doctor Wright applied this haze penetration to the photography of Mars at the last opposition, photographing the planet on an ordinary plate and also upon a Kryptocyanine plate with a filter, and he obtained the very remarkable result shown in Fig. 15. It is seen that the image of the planet by violet light is actually considerably larger than in the photograph taken by infra-red light. All corrections were made for other optical effects, and it was concluded that this enlargement was due to the scattering of the shorter waves by the atmosphere of Mars, a photograph taken by violet light representing the outside of the atmosphere of Mars, while a photograph taken on the Kryptocyanine plates represents the surface of the planet. This is borne out, of course, by the markings of the surface which are well shown

FIG. 14.

Panchromatic No. 25 filter. λ600—λ700.

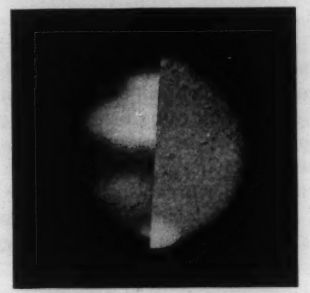


Kryptocyanine No. 70 filter. λ700—λ800.

Neocyanine liquid filter. λ850—λ900.
Photographs taken by long-wave radiation.

in the Kryptocyanine plate, while they are practically invisible in the violet photograph. The result of this work has been to change the viewpoint of the astronomers with regard to the atmosphere of Mars. It had always been thought that Mars had either no atmosphere at all or a very shallow one. It appears now that the atmosphere of Mars is many miles deep. It is probably not a dense atmosphere, though it is largely devoid of water vapor. The characteristic difference between Mars and the earth is not the absence of air from Mars, but the much smaller amount of water found on Mars, which leads to an absence of liquid seas and to a smaller degree of cloudiness. It is possible that the scat-

FIG. 15.



Comparative photographs of Mars, taken with an ordinary plate and an extreme red-sensitive plate with filter.

tering power of Mars is due not to water vapor or even to the molecules of the gas, but to dust. A nearly waterless planet whose components are represented by large, high, plateau-like deserts would probably throw into the air vast quantities of yellowish dust, and it is not improbable that it is this which gives the characteristic color to the planet.

Partly as a consequence of the great extension of the spectrum which is possible with photographic as compared with visual observation, photography is extending more and more to supplant the eye as an observing instrument for scientific work. Owing to the fact that the refractors are corrected for visual use, the plates used are generally those sensitized with Erythrosin, and a yellow filter is used to remove the blue, so that the photograph is made in the photo-visual maximum. Comparisons are made

upon the magnitude of stars as recorded by violet light and by this photo-visual light with an average wave-length of λ560, and the ratio of magnitudes is termed the *color index,* and has been used very largely as the means of classifying stars, the stellar classes, which depend primarily upon the spectrum, being indicated by the magnitude of the color index. In view of the availability of Kryptocyanine, it seems not unlikely that in the future another measurement will be made with an average wave-length of λ750, thus enabling better classification to be obtained without actual measurement of the spectrum.

The spectroscope has, of course, been a photographic instrument almost from the beginning, the visual spectroscopes so well illustrated in the text-books being little more than toys. Until quite recently, however, the microscope has remained a visual instrument, the photomicrographic methods being employed only to depict what had already been seen. It seems likely that before long the microscope in its turn will become a photographic instrument, the visual observation being used only to guide the instrument to the photography of the unseen. The reason for this is the necessity for greater resolving power, especially in connection with photography of the smaller organisms which are classed as filter passing bacteria and bacteriophages. The distance between the separation of two lines which can just be shown separately is given by the equation

$$d = \frac{\lambda}{2\,NA}$$

The distance between the two lines is equal to the wave-length divided by twice the numerical aperture. Now, we have probably reached the limits of numerical aperture when we use oil immersion objectives with a numerical aperture of 1.4. It is only by the use of special mounts that we can employ monobromnaphthalene immersion at an aperture of 1.6, and this is very limited in its application. In order to get increased resolving power, therefore, the only path that lies open before us is to diminish the wave-length.

In the interesting work of Barnard and Gye on the cancer virus, concerning which so much has been heard lately, Barnard made use of the ultra-violet microscope developed by Kohler, of Zeiss, using a wave-length of λ257 and a numerical aperture of 1.25, and obtained a resolving power of .11μ as compared with .2 available to the eye working with a wave-length of λ560 and

a numerical aperture of 1.4, or of .16 available photographically by the use of λ450 with the same objective.

It is perhaps questionable whether the use of the quartz instrument is worth while for the gain it gives. If photographs are taken with wave-length λ360 mercury and a numerical aperture of 1.4, a resolving power of .129 is available and the distance from .13 to .11 scarcely seems to justify the great difficulty involved in making the whole system of quartz. Barnard, however, is undoubtedly trying to get shorter wave-lengths, and if he could use a wave-length of λ185 with a numerical aperture of 1.25, he could get .075 resolving power and that might be an advance of the utmost importance for bacteriology. Of course, this involves a great deal of difficulty. The line at λ185 given by the aluminum spark or the mercury arc is absorbed by three millimetres of air, and consequently the whole instrument from the source to the photographic plate would have to be worked in vacuum. Quartz has a considerable absorption, and it may be necessary to construct some parts of the instrument of fluorite. The difficulties are many, but the end is worth while.

Magnetostriction in Iron Crystals. W. L. WEBSTER. (*Proc. Royal Soc.*, A 7520.)—The author was fortunate in having at his disposal some large crystals of iron containing only ½ per cent. impurities. From these, rods were cut parallel to the (1, 0, 0), (1, 1, 0) and (1, 1, 1) directions. The length was about 18 mm. and the diameter 1.2 mm. These rods were magnetized longitudinally in a solenoid. A combination of optical and mechanical levers magnified the changes of length, thereby produced by 5×10^4. The intensity of magnetization and the magnetic field were also determined. The effect of magnetization upon the dimensions of iron was quite different in the three directions. For the (1, 0, 0) axis an increase of length manifested itself at 30 gauss. The length continuously increased up to the maximum magnetizing field applied, 600 gauss, where the rod was 20 millionths longer than at the beginning. In the (1, 1, 1) direction a contraction appeared at 90 gauss and became greater and greater with increasing field, though for every strength of field it was smaller than the corresponding increase of length in the (1, 0, 0) direction. Along the (1, 1, 0) axis the results lie between those obtained for the other two axes. Beginning with 50 gauss the length increases with the application of stronger fields. For 150 gauss the maximum length is attained. The contraction which follows brings the specimen back to its original length

at 475 gauss. Further increase of field causes the length of the rod to become less than it was before the application of any field. For all three directions there was no sign of the length becoming constant, and therefore independent of the field.

A piece of soft-iron rod followed quite closely in its length changes the comportment of the (1, 1, 0) axis. "It is interesting to note that the shape of the curve for soft iron can be explained by the combination of the different types of effects found for single crystals. In soft iron there is probably a heterogeneous mass of small crystals, with a random distribution of their axis. The initial increase in length for soft iron would be expected, as it is seen that the increase in length begins at an earlier stage than the contraction. The final contraction is explained by the fact that only the few elementary crystals having a tetragonal axis near the axis of the iron rod, would contribute to the general effect, an increase in length when saturation is approached, and that this contribution would be overwhelmed by the contraction effect of the rest of the rod. It is seen that the magnetostriction effect will depend very greatly on the exact crystalline structure of the specimen examined, and will be greatly changed by any treatment which alters the crystalline structure."

The effect of tension on magnetic intensity was examined. The three rods above discussed were magnetized and then tension was applied. The change in magnetic intensity was measured. For the (1, 0, 0) axis an increase in intensity followed, for the (1, 1, 1) axis a decrease and for the (1, 1, 0) axis the sign of the effect changes.

G. F. S.

On the Bending of Crystals. C. H. BOSANQUET. (*Proc. Phys. Soc. London*, Dec. 15, 1925.)—In 1903 Coblenz found that he could bend slips of rock salt provided they were immersed in strong brine at 50°–70° C. The brine can be replaced by mere hot water. It is thus possible to bend into a semi-circle a slip 15 × 5 × 2 mm.

In order to discover what takes place within the crystal when it bends, the author reflects X-rays from it. He interprets his results to be in agreement with Joffé, that "the process of bending consists of the breaking down of the crystal into small units, which slip along rhombododekehedral planes and in addition turn through various angles." The function of the surrounding hot liquid seems to be to prevent the formation of cracks. It fills at once any fissure that develops. Since it is saturated with respect to a plane surface and at the same time is supersaturated with respect to a concave surface, it can deposit solid salt in the crack at the point of greatest stress. Thus the tensile strength is increased. Other observers have found the tensile strength of the dry crystal to be 450 g. per sq. mm. and of the crystal in water 4000 g.—nine times as much. G. F. S.

THE SPECTROSCOPY OF THE EXTREME ULTRA-VIOLET.*

BY

THEODORE LYMAN, Ph.D.

Director, Jefferson Physical Laboratory; Professor of Physics, Harvard University.

A REVIEW.

SOME four years ago, in an address given before the American Physical Society,[1] I reviewed the state of our knowledge of radiations in the extreme ultra-violet region of the spectrum; I propose to devote part of the present paper to a description of some recent developments in this field. Before taking up the matter in detail, however, it will be well to say something on the nature of radiation in general to the end that we may understand the relation of the region under discussion to the spectrum as a whole. It will also be appropriate to present some of the facts that justify confining the subject to what may appear at first sight a rather limited field.

Light has been described as a periodic phenomenon propagated with a finite velocity; if we are content to follow this definition we may use this one word to suggest the common quality of electric waves on the one hand and X-rays on the other.

The exact relationship of the various radiations in question is made clear by a diagram plotted in terms of the logarithm of the wave-length (Fig. 1). Beginning with waves such as are used in wireless telegraphy, we may progress in a continuous manner into the region whose study forms the subject of this paper. The range of wave-lengths reaches from several hundred metres on the one hand to about 2×10^{-8} metres on the other. The numerical extent of the region may be more easily grasped if the scale be so changed that our shortest wave-length is represented by two millimetres when it will appear that the electric wave-length will correspond to about 3×10^{7} metres or 20,000 miles.

The properties of what we have called light have been experimentally determined from one end of this vast region to the other by methods which rest on the classic analysis first introduced to account for the properties of visible radiation. If an example

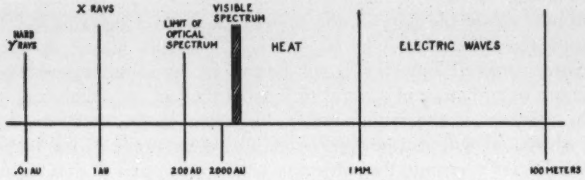
* Presented at the Stated Meeting held Wednesday, February 17, 1926.

[1] *Science*, 55, 161, 1922.

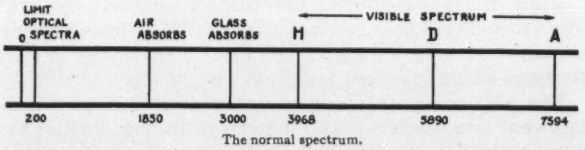
is required it is only necessary to remember that the principle of the diffraction grating is employed in the Schumann region on the one hand and in the experiments of Nichols [2] and Tear on electric waves on the other.

Progress then is continuous until we reach the region of extremely short wave-lengths at a point near 2×10^{-8} metres or, to use the language of the spectroscopist, near a wave-length of 200 Ångström units. At this point a definite break may be said to occur; for as yet it has been found impossible to make use of

FIG. 1.



The electromagnetic spectrum on a logarithmic scale.



The normal spectrum.

methods of spectroscopic analysis founded on diffraction and interference in the region.

Many attempts have been made to cross the gap by indirect attack; but they all rest on distinctly different principles from those employed in optics. Briefly stated, the process consists of detecting the presence of the radiation in question by means of the photo-electric effect which it produces, the wave-length being estimated from the formula of Einstein, $Ve = h\nu$. For further details the reader cannot do better than consult a recent paper of O. W. Richardson.[3]

While such investigations are important and suggestive, they are not entirely conclusive. All things considered, I think it is

[2] *Astrophys. J.*, 61, p. 17, 1925.

[3] *Proc. Roy. Soc.*, A 110, No. 754, p. 247, 1926.

not over-conservative to say that the region of the extreme ultra-violet is still bounded by a kind of no-man's land; narrow, if its extent be expressed in wave-lengths, but very difficult to cross, at least by the kind of conveyance which has served so well in our long journey from the region of wireless telegraphy.

Once across the debatable ground we enter the region of the X-rays. Here at least some of the principles of the classic wave theory hold sway and we can determine our position in terms of wave-lengths by methods of diffraction and of interference identical in general theory with those employed in the visible. True, it has generally been necessary to rely upon the crystal lattice for the grating with which to carry on our analysis of these shortest wave-lengths. Recently, however, the required results have been obtained by the use of exactly the same kind of instrument invented so long ago by Fraunhofer, for A. H. Compton[4] has succeeded in measuring the wave-length of X-rays by means of a plane diffraction grating ruled on metal. This important experiment involves another principle besides that of diffraction, for the X-rays in their reflection at a metal surface not only exhibit the same general behavior as visible light totally reflected in going from a more to a less dense medium, but also illustrates the well-known relations between absorption and refraction.

Successful experiments involving reflection and refraction of X-rays have also been made by Siegbahn and some others, while Thibaud,[5] in Paris, guided by Compton's analysis, has very recently made wave-length measurements with a glass grating.

The development of that part of spectroscopy which is concerned with atomic structure must serve as the chief excuse for directing attention to the field with which the rest of this paper is occupied. Interested at first solely with the insignificant range of the visible, the spectroscopist soon pushed on into the ultra-violet. His labors were hampered by the opacity of the glass of which his instruments were constructed, and when this difficulty was overcome by the substitution of quartz, he was again checked by the opacity of the air itself. It was Victor Schumann who opened the way into the extreme ultra-violet with prisms and lenses of fluorite and a vacuum spectroscope.

In tracing the advance of subsequent investigators, I intend to

[4] *Proc. Nat. Acad.*, **11**, No. 10, p. 598, 1925.
[5] *Comptes Rendus*, **182**, No. 1, p. 55, 1926.

confine myself, as I have already said, to the progress of the last few years. But first by way of clearness it will be well to describe a modern type of instrument with which investigations in the region between λ1800 and λ200 are carried on.

A concave diffraction grating,[6] usually of about one metre radius, is placed in a receiver from which the air is exhausted. Long study has shown that this receiver should be maintained at a high vacuum; this is a point of the very first importance. On the other hand, for most purposes the pressure at the source of light cannot be very low, matters must be so arranged therefore that the gas which fills the discharge tube is not allowed to enter the body of the spectroscope. The result is secured by separating the source from the rest of the apparatus by a narrow and short slit and by applying a very powerful pump at a point just inside this slit.

The idea which underlies the arrangement was suggested to me a good many years ago, but my attempts to carry it into practice failed because sufficiently rapid pumps were not in existence at the time. The invention of the mercury diffusion pump, together with a copious supply of liquid air, enabled both Professor Hopfield and myself to apply the idea with success. The incident forms a good example of the influence which improvements in mechanical accessories have upon the progress of research.

But to return to more general considerations. When ways and means were devised for extending the spectrum into the region of very short wave-lengths, spectroscopists began to follow their problems into the new territory. No one who knows anything of the progress of modern physics can have failed to recognize the extraordinary advances which have been made in our knowledge of the construction of spectra, an advance so fundamentally stimulated by Bohr's atomic model. The investigations of the modern spectroscopist therefore deal chiefly with the study of spectral series. It is problems of this type which have been carried into the extreme ultra-violet, and with which we are chiefly concerned in giving an account of what has recently been accomplished in this region. Obviously enough the subject on any considerable scale is far beyond the scope of this paper; I believe, however, that by confining myself to a few simple

[6] LYMAN, *Astrophys. J.*, **60**, No. 1, p. 1, 1924.

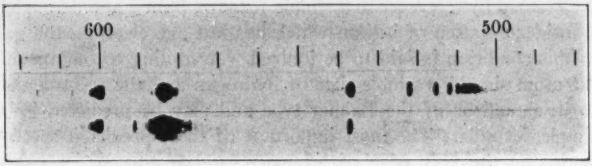
examples, I may illustrate how the Schumann region has come to be an important field for modern scientific enquiry.

The orderly arrangement of the lines in the Balmer series in hydrogen is easily seen, particularly if we study the spectra of certain stars; the equation which expresses the relation between the frequencies of these lines is

$$V = N\left[\frac{1}{2^2} - \frac{1}{n^2}\right] \quad n = 3, 4, 5 \text{ etc.}$$

Now the point that particularly interests us is this: If for the figure 2 we substitute 1, we obtain an expression easily interpreted on Bohr's model, and which indicates a spectral series in hydrogen in the extreme ultra-violet. This spectrum has been

FIG. 2.



A series in the spectrum of normal helium in the extreme ultra-violet.

discovered; its first member lies at λ1216. Here let us pause long enough to recall that on this scale the end of the visible lies near λ4000 and the absorption of air begins near λ1850.

Going one step in the periodic table we come to helium. The spectra of the normal element are by no means so simple as those of hydrogen, their lines, however, may be arranged in two sets of series, obeying equations of the same general form as that which describes the Balmer series, though more complicated in detail. A change in the first term of one of these equations, somewhat similar in character to that which has just been described for hydrogen, leads to a relation which predicts a helium series in the extreme ultra-violet. This series has been discovered. Its appearance is striking and characteristic. Its limit lies pretty well out toward that no-man's land of which we have already spoken (Fig. 2).

Here it is interesting to note that series relations in the region of extremely short wave-lengths are generally simpler and more

easy to recognize than those in the more accessible parts of the spectrum. Normal helium furnishes one example, as we have just seen. Another striking case is furnished by neon whose complex series were only disentangled by Paschen after much labor; the short wave-length spectra of this gas, however, are relatively simple as a paper by Professor Saunders [7] and myself has recently shown; Hertz [8] has also confirmed our results.

In general then, study of series spectra in the visible and ultra-violet leads to the prediction of new series relations in the extreme ultra-violet. The verification of these predictions is a matter of considerable interest. This is the first topic to which I wish to direct attention.

The second has to do with enhanced spectra. Here the fundamental ideas are of great importance. They are most easily understood by reference to a simple form of Bohr's atomic model. Consider an atom of helium which has lost one electron, the gas in this condition is said to be ionized. According to our model, the atom should resemble that of hydrogen and the spectra, due to it, should be of the Balmer type and may be predicted by a simple formula. The most important of these predicted spectra begins on the very edge of no-man's land at $\lambda 303.6$; [9] another has its first member at $\lambda 1640$; both of these spectra I have discovered. This is the simplest possible example of what are called enhanced spectra. With elements of higher atomic number such as silicon or nitrogen, distinct sets of enhanced spectra exist, each set corresponding to a particular state of ionization. In general, Bohr's theory predicts that as the degree of ionization increases the corresponding spectra will move further and further into the extreme ultra-violet. It is for this reason that their study carries the modern spectroscopist into the region under discussion.

Naturally many investigators have carried on the larger part of their work in the visible and ultra-violet and are only driven to the region of extremely short wave-lengths by necessity. Fowler [10] with his important work on the spectra of silicon at successive stages of ionization affords an excellent example of

[7] *Proc. Nat. Acad.*, 12, No. 2, p. 92, 1926.
[8] *Zeits. f. Phys.*, 32, p. 933, 1925.
[9] LYMAN, *loc. cit.*
[10] *Proc. Roy. Soc.*, A 103, p. 413, 1923. *Nature*, 113, p. 881, 1924.

this type. I myself have done something of the same kind by verifying predictions made by Paschen in the spectra of aluminum and magnesium.[11]

Then there are investigations which are chiefly concerned with the accumulation of data without direct reference to any theory. The accurate and useful studies of L. and E. Bloch[12] on the spark spectra of many elements are of this type. The region which they have covered is, however, limited in extent by the nature of their apparatus, a fluorite prism spectroscope.

Lang,[13] by employing a vacuum grating spectroscope of the kind designed at Toronto, has made measurements on the spark spectra of twenty elements down to the extreme limit of the optical region. Ireton,[14] Shaver[15] and Weinberg[16] have also studied metallic spectra in the extreme ultra-violet.

The work of Simeon[17] is noteworthy, not only because it yields accurate wave-length determinations of the carbon spectrum, but also on account of the observations on the relation between depth of ruling and strength of spectra. His results emphasize the advantage of light ruling in gratings designed for use in the extreme ultra-violet; a conclusion which has been confirmed by Millikan and by myself.

In this connection it is well to emphasize the debt which spectroscopists owe to R. W. Wood[18] for his labors in resurrecting the ruling engines at Johns Hopkins University; and for the learning and skill which he has displayed in exorcising the ghosts which haunted these historic machines. As an example of the quality of results which may be obtained from the new dynasty of gratings one cannot do better than examine the definition in the spectrograms obtained by Professor Wood with a vacuum spectroscope.

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[11] *Science*, **60**, p. 388, 1924.

[12] *Comptes Rendus*, **172**, pp. 803, 851, 962, 1921; **177**, p. 1025, 1923; **178**, p. 472, 1924; **179**, p. 1396, 1924; **180**, p. 133, 1925. *Jour. de Phy. et le Radium*, **2**, p. 229, 1921; **6**, pp. 105, 154, 1925.

[13] *Phil. Trans. Roy. Soc. Lond.*, **224**, p. 371, 1924.

[14] *Proc. Trans. Roy. Soc. Canada*, **18**, III, p. 103, 1924.

[15] *Proc. Trans. Roy. Soc. Canada*, **18**, III, p. 23, 1924.

[16] *Proc. Roy. Soc. Lond.*, **107**, p. 138, 1925.

[17] *Proc. Roy. Soc. Lond.*, **102**, p. 484, 1923; **104**, p. 368, 1923.

[18] *Phil. Mag.*, **46**, p. 741, 1923.

Hopfield,[19] a modern explorer of the extreme ultra-violet, has published several important papers during the last four years, dealing with the spectra of hydrogen, nitrogen, water vapor and air both in emission and absorption, and with some very interesting series relations in the spectra of oxygen. With Leifson he has published a table of standard wave-lengths. Recently he has made a report on series in the spectra of sulphur and of chlorine and upon the ionization potential of the latter gas.

Accurate and systematic work in this region is also well illustrated by a recent paper by J. A. Carroll[20] on the spark spectra of some of the heavier elements.

A short note by E. P. Lewis[21] on the continuous spectrum of hydrogen to $\lambda 1750$ is of particular interest to me at present, as I am engaged in the study of the conditions under which continuous spectra are produced in the extreme ultra-violet. It is curious that Professor Lewis finds a single discharge of low-current density most suitable, at least in the least refrangible end of the Schumann region.

Though no startling progress has been achieved, a word on the photographic technique employed may be of interest. The photographic plates made according to the method described by Schumann are still indispensable. Duclaux and Jeantet,[22] however, have suggested that a common plate may be sensitized for the extreme ultra-violet by the application of a thin coating of oil. So far the process has not yielded results comparable with the older procedure, but I think its possibilities have not been fully explored.

While many investigators have been led into the extreme ultra-violet by following the study of the laws of series spectra first begun in the region of longer wave-lengths, Millikan's important spectroscopic speculations may be said to have originated in the Schumann region. His earlier papers during this epoch dealt with an extension of the Moseley rule into the domain with which we are concerned. By selecting certain strong lines in the spectra

[19] *Phys. Rev.*, **18**, p. 327, 1921; **19**, p. 548, 1922; **20**, p. 573, 1922. *Nature*, **110**, p. 732, 1922; **112**, p. 437, 1923. *Astrophys. J.*, **58**, p. 59, 1923; **59**, p. 114, 1924. *Phys. Rev.*, **21**, p. 710, 1923; **26**, p. 282, 1925. *Bull. Am. Phy. Soc.*, **1**, No. 8, p. 9, 1926.

[20] *Phil. Trans. Roy. Soc. Lond.*, **225**, p. 357, 1925.

[21] *Phys. Rev.*, **16**, p. 367, 1920.

[22] *Science*, **58**, p. 48, 1923.

of the lighter elements, he endeavored to show that the relations which connect frequency and atomic number in the X-ray region also hold in optical spectra. His conclusions rested on a great deal of experimental data which he and his collaborator, Doctor Bowen, accumulated between λ200 and the visible. More recent investigations have indicated that his earlier identifications were not correct in all cases, but the main idea remains one of interest and importance. The later work of Millikan [23] and Bowen has been even more fundamental than their earlier speculations. They have succeeded in showing that the law which connects the separation of regular X-ray doublets with atomic number holds for the lighter elements throughout the spectrum. They have demonstrated the applicability of a rule by which the position of irregular doublets may be predicted from element to element, a rule which had its origin in the study of X-rays. Finally they have applied their investigations of series relations in general and of the doublet laws in particular to a criticism of some of the basic principles of Bohr's atomic theory. All this work has been chiefly carried on in the region of extremely short wave-lengths, thus a study of what is at first sight a rather limited field has yielded results of high importance to spectroscopy in general.

In conclusion it may be worth while to say a word on the short wave-length limit of this particular part of the spectrum. It is my personal opinion, founded on my own experiments, that wave-length two hundred is probably about the end of optical spectra as obtained with a concave grating. When we turn to the question of bridging the gap between this point and the limit of X-ray spectra set by the investigations of Professor Thoræus [24] near 20 Ångströms, I think we may look with hope to Prof. A. H. Compton's grating experiments which have already been described.

At all events I trust I have made it plain that the interest in the extreme ultra-violet and its frontier is steadily increasing. To those who demand that research shall show results of imme-

[23] *Phys. Rev.*, **23**, p. 1, 1924; **24**, p. 209, 1924; **24**, p. 223, 1924; **25**, p. 295, 1925; **25**, p. 591, 1925; **25**, p. 600, 1925; **26**, p. 150, 1925; **26**, p. 310, 1925; **27**, p. 144, 1926. *Phil. Mag.*, **48**, p. 259, 1924; **49**, p. 923, 1925. *Proc. Nat. Acad.*, **10**, p. 199, 1924; **11**, p. 329, 1925. *Nature*, **114**, p. 380, 1924; **115**, p. 422, 1925.

[24] *Phil. Mag.*, **1**, p. 312, 1926.

diate benefit to humanity our field may not seem important. But let us remember the fact, established by the history of science, that time and effort spent in the accurate and intelligent observation of nature is never spent in vain. So fortified, we may look forward to the possibility that ultimately the study of the extreme ultra-violet may result in something directly useful to mankind.

Critical Observations upon the Repetition of Michelson's Experiment on Mount Wilson. HANS THIRRING, Vienna. (*Zeit. f. Phys.*, **35**, No. 10, 1926.)—From some thousands of observations made by him on Mount Wilson, Dayton C. Miller in 1925 announced the conclusion that there is an ether-drift at that elevation of 9 kilometres per second. Such a result has been interpreted as antagonistic to the theory of relativity if, indeed, not fatal to it. Hence we may expect much discussion until a final decision is reached.

It has been suggested that Miller's experimental results, as also the well-established deviation of light rays passing near the sun, are explained by the ether theory of Stokes and Planck. This view is opposed by the author who holds that "if the effect found on Mount Wilson cannot be referred to hitherto unexplained sources of error, it confutes not only the special theory of relativity, but also the theories of Fresnel and Stokes." From the absence of longitudinal waves it has been inferred that the ether is incompressbile, yet to explain the deviation of light by the sun it is calculated that the ether, now assumed to be compressible, at the disc of that body has a density 10^{12000} times as great as at a great distance from it. The author emphasizes the incompatibility of these conclusions. Our confidence in his strictures would be greater were it not for an addendum in which admission of an error in the statement of the Stokes-Planck theory is made.

A comparison of Miller's results with predictions based on theory is made and divergence is shown. The author throws out the suggestion that it would be well to repeat the experiments at Pasadena at the foot of Mount Wilson in order to find whether the same effect is existent at sea-level in the vicinity of the mountain. G. F. S.

SCIENCE AND THE EARTHQUAKE PERIL.*

BY

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INTRODUCTION.

NOT all of us agree with the European geologist, Suess, who made a great effort to prove that the flood of Noah was due to the combination of a hurricane and a seismic sea wave or so-called "tidal" wave resulting from an earthquake. His argument is that a flood due entirely to rain would in the Euphrates Valley have driven the ark to sea, whereas it went into the mountains. However, we know that the earthquake peril far antedates recorded history, and that primitive man, like his modern successor, was brought to realize his helplessness in the presence of such forces.

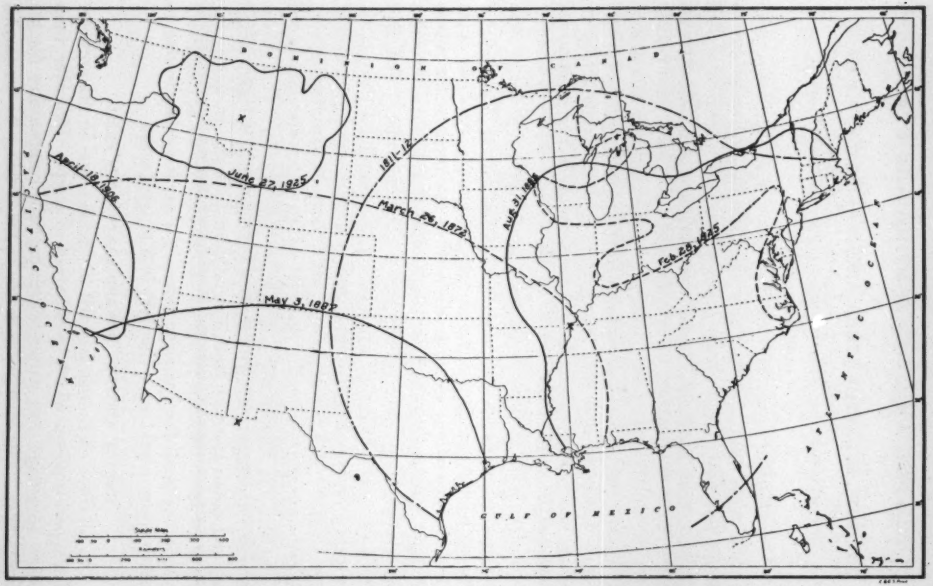
Earthquakes have never shown discrimination insofar as man is concerned. They occur out in the desert or beneath the crowded city with equal impartiality, though fortunately most of them have occurred where they can do little or no harm to the works of man. One earthquake may have destroyed a Tokio or Messina and another may have interrupted a cannibal feast. The San Francisco and Charleston earthquakes are familiar to everyone. Probably, Seattle, Wash., had a similar disturbance in the distant past (Fig. 1). A few years ago the Coast and Geodetic Survey located and assisted in the removal of an extensive submerged forest in Lake Washington, which adjoins Seattle. This forest consisted of many acres with trees standing nearly upright, which had slid down in mass from the adjacent island. It seems that this must have been the result of an earthquake, as any ordinary transfer of land down a slope, even in a great avalanche due to other causes, would leave the trees in a tangled mass.

MENTAL ATTITUDE TOWARD EARTHQUAKE PERIL.

In all these cases man has felt his helplessness in the presence of a superior power which he is forced to accept. However, man has an advantage over nature which partially compensates for his helplessness. The earthquake is due to the inability of the earth's

* Presented at the Stated Meeting held Wednesday, March 17, 1926.

FIG. 1.



Approximate limits of felt disturbances from great earthquakes (also 1925 earthquakes) in the United States.
Key.—1811–1812, New Madrid (Mo.); March 26, 1872, Owens Valley (Calif.); May 3, 1887, Sonora (Mexico); August 31, 1886, Charleston (S. C.); April 18, 1906, Northern California; February 28, 1925, St. Lawrence Valley; June 27, 1925, Gallatin County (Mont.).

crust to stand the strains imposed on it. Nature does nothing and can do nothing to remedy this condition, except perhaps to increase the stability after a long geological period. The damage to the structure of man by an earthquake is due to their inability to resist such sudden strains. Unlike nature, however, man can improve his structures so that they will resist all but the tremendously severe earthquakes which occur only at intervals of several centuries.

This brings out clearly the fact that even in the presence of greater forces than any he can evoke or control, the mind of man is not entirely helpless. There are defects in human character, however, that aid greatly in allowing the earthquake to overcome reason. Fatalistic religions are in part due to natural occurrences which show man his helplessness and lead him to believe that he has no chance to shape events. Earthquakes are a strong contributing cause to the spread of such religions. The danger of the fatalistic attitude is that no provision is made for the future. As earthquakes recur in the same localities at greater or shorter intervals the same catastrophe to human life and property is likely to occur over and over, even where the religion is not fatalistic, unless new precautions are taken. A case in point is that of Messina, which has rebuilt at least three times after almost complete destruction, and many times after partial destruction. Probably the only changes at each reconstruction have been those imposed by architectural styles, and not with any idea of resisting destruction by earthquakes.

Men are also intensely conservative and are likely to continue to do the very thing to invite disaster. We Americans have little right to criticize the attitude described, as we have not only done the things mentioned, but after a great earthquake have tried to ignore it and make it appear that it never occurred. This attitude is rapidly fading before a recognition of its futility, its invitation to future disaster, and a realization that Americans, like other people, are willing to face what may come.

I quote the following from President Bailey Willis, of the Seismological Society of America, in the Seismological Bulletin: "There are a good many ways of regarding the danger from earthquakes. It may be ignored or ridiculed, prayed against or fled from, or examined and guarded against. It is, however, useless to ignore a blow which is sure to fall, and foolish to

ridicule that which has the power to destroy us. Prayer, though long and devoutly practiced, has not averted shocks, even from sacred edifices and their congregations; and he who flees ignorantly is quite as likely to run into danger as out of it. The only safeguard against the forces of nature, whether they be lightning strokes or earth tremors, is understanding, by virtue of which we may be forearmed because forewarned."

His statement, and indications from other sources make it appear that in spite of the mental inertia which has been brought out, a state of mind is now developing which is favorable to an organized attempt to solve the problems in a scientific manner.

EARTHQUAKE ACTIVITY NOT LIKELY TO CHANGE.

There is little reason to expect change in the proportion of area affected, which is very small compared with the total area of the earth, and the effect on such area is not likely to change greatly. That is, the areas will not always be the same, but the total effect on the earth is not likely to change to any important degree. The human race in the past adapted itself in part to the condition, and until recently the greatest earthquakes caused loss of life and property in amounts no greater than those from many other forms of catastrophe. This condition still holds for much of the earth's surface. The earthquake which occurred in the Solomon Islands, in the Pacific Ocean, in January of this year, probably, except for the presence of a limited number of Europeans and a higher degree of agricultural development, had little more effect than would have a similar earthquake 1000 years ago. Submarine earthquakes caused little more damage, except in the case where large seaports are damaged by tidal or seismic sea waves.

INCREASE OF EARTHQUAKE PERIL.

There are, however, many parts of the earth where the possible effect of earthquakes on the works of man has greatly changed. These include the highly civilized portions and also those formerly less civilized, but which have become occupied by reason of the increased density of population. It is not only the increased density, but the adoption of types of structures of greatly increased complication and size, and the necessity of various kinds of structures beneath the earth's surface which have changed the fundamental conditions.

The New Madrid earthquake of 1811–1812 was among the greatest that have ever occurred, and yet the damage to human life and property was insignificant. The immediate vicinity of New Madrid would not have a great loss of life and property from a similar earthquake of the present day as the country is still relatively unsettled, but it seems likely that St. Louis and Kansas City would at least be shaken sufficiently to throw down old and poorly constructed buildings, and to shake cornices from buildings. The great Quebec earthquake of 1663 affected comparatively few people and did little damage, except to the surface of the earth. The very much milder disturbance of February, 1925, did considerable damage and succeeded in at least frightening millions of people. It is now recognized that panic is one of the greatest dangers in great cities, especially those with a large percentage of foreigners who cannot speak English.

An example of quick change, from an unsettled region to one generally though thinly settled, is the case of Alaska. The great Yakutat Bay earthquake of 1899, which caused the largest vertical change ever recorded on land, passed scarcely noticed and it was several years before reports of any special value were received. A relatively small earthquake which occurred in Western Alaska in February, 1925, was published within twenty-four hours, and within a month quite adequate information was available at Washington as a result of collection of reports by the Coast and Geodetic Survey.

INCREASING COMPLEXITY OF STRUCTURES.

These illustrations bring out the effect of increasing density of population. The increasing complexity of structures is quite as vital a factor of the problem. Probably we all know the facts, but it may be well to enumerate them. In the colonial days of New England there were many fairly severe earthquakes. The buildings were compact, strongly built, and had no auxiliary piping or wiring. Their only weak point was the construction of chimneys, which in many cases were of round boulders with poor mortar. The usual result of an earthquake was the fall of chimneys with little or no other damage. Each house was sufficient to itself insofar as water supplies, fuel, sewage, etc., were concerned.

To-day most buildings have become something more than

shelters. Their size has grown rapidly from the early days when city buildings rarely exceeded two stories. In many cases too little care has been exercised in using details of fastening which make it possible for the buildings to resist earthquake strains. The earthquake is particularly adapted to destroying these structures and this has become one of its chief menaces. It is, for example, an ideal method of starting a fire and preventing its extinction in a way that the most ruthless army bent on destruc-

FIG. 2.

Rupture of 30-inch water pipe by fault during California earthquake of 1906. (According to State Earthquake Investigation Committee.)

tion of a great city could not hope to emulate. Potential danger exists in the average structure containing water and gas pipes, electric lines and heating equipment. Overturning of heating units, and breaking of electric or gas lines will generally result in fire, besides presenting additional danger to fleeing occupants. Rupture of the great mains and transmission lines which make these facilities possible will introduce wholesale menace from fire, extinction being difficult from lack of water. Broken mains may require a considerable time for repairs, resulting in such an interruption of service as to imperil the health of the community. (Fig. 2.)

Parked automobiles present a fire hazard with their ever-

present tanks of gasoline, as also do the greater supplies of the filling stations. Dangerous chemicals may be freed from piping in factories. Transportation may be hindered greatly by destruction of bridges, tunnels, subways, and railroads, all of which will prevent escape from the danger zone and delay the arrival of supplies, relief workers, and other vital aids.

It is clear, then, that the complexity of modern civilization is such that absolute dependence is placed on the continuity of certain services. This requires careful design of the various types of structures and equipment in order that they may offer the greatest possible resistance to endangering stresses.

One of the important uses that can be made of these great catastrophes is to study them carefully to see what lessons can be drawn for the prevention of damage in the future. It has been brought out that the peril varies with the density of population and complexity of structures and this is strikingly emphasized in certain earthquakes.

EARTHQUAKE PERIL IN LARGE CITIES.

The San Francisco earthquake of 1906 occurred before some of the complexities of the present time had developed. The automobile and large gasoline supplies were not a factor. On the other hand, structural design and materials had not advanced as far as at present. However, many of the problems were identical with those of the present time. Fire was the chief cause of loss of life and destruction of property, though of course the earthquake was responsible for the fire and the prevention of its extinction. In this case the great percentage of frame buildings and breaking of water mains were the outstanding features. Both of these problems will yield in a large measure to attack from correct scientific principles. It may be necessary to abandon the frame structure for buildings in close contact, but this is not unthinkable with the reduction of the lumber supply. The correct placing of water mains and reservoirs may require a large amount of detailed study of geological substructure. In the San Francisco earthquake the survival of the City Hall tower, which was mounted on a separate, well-designed steel structure, while everything else was in ruins, was an early, outstanding indication of the right course to be followed. (Fig. 3.) This has been too little considered.

The Tokio-Yokohama disaster of September, 1923, presents somewhat different conditions. Here the poverty of large masses of the people necessitated a type of building which was absolutely unsuited to meet the earthquake peril in a large city, though well suited to the open country at such times. Here again the earthquake damage, though great, was entirely overshadowed by that

FIG. 3.

Ruin of the $7,000,000 City Hall, San Francisco, by earthquake and fire. (According to U. S. Geological Survey.)

of the fire. It had been supposed that park spaces would be a great safeguard and refuge, but in Tokio the fire was so intense that vast throngs perished in the parks. The lesson is that the number of inflammable structures must be reduced. The strongest measures should be taken to secure this by means of rigid building codes. It may even become necessary for state or municipal governments to aid in reconstruction in order that rebuilding may be of the right type. Ornamental features, such as cornices, should be omitted. Japan has had a lesson in the futility of one type of architecture which illustrates this point. Use of tile roofs on light structures proved entirely satisfactory

till the earthquake came. Then the tiles became a deadly menace. Under the conditions mentioned for the Japanese cities the failure of water supplies was a particularly bad feature. It may be of interest to mention in connection with this earthquake that the Japanese seismologist, Imamura, kept his instruments in operation in spite of earthquake and danger from fire to the building in which the instruments were located.

EARTHQUAKE PERIL IN SMALL CITIES.

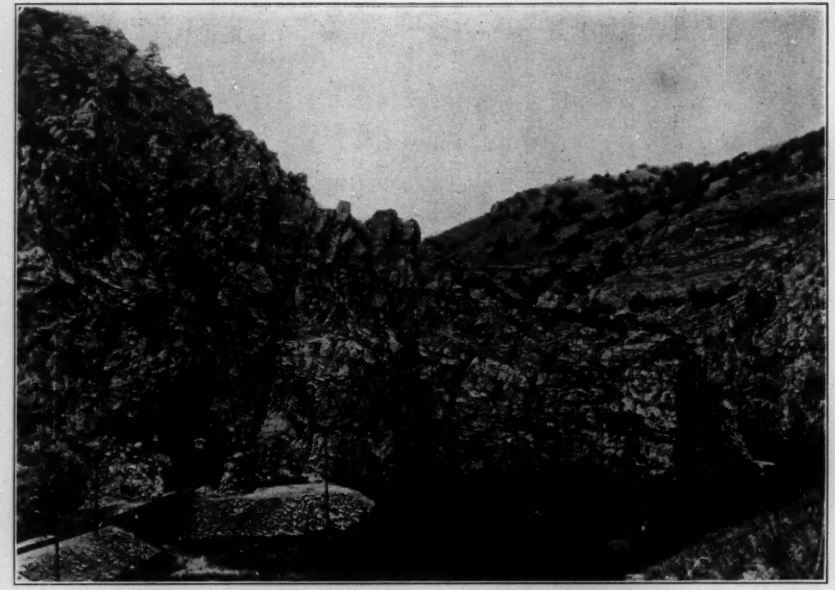
The number of great cities is limited and while they have the greatest possibilities of destruction and great loss of life, they cover comparatively little area and most of them are in regions reasonably exempt from earthquakes. We have, however, the problem of the small cities or towns which are scattered over a very wide extent of territory. While not so highly organized, they are smaller reproductions of the larger cities and have similar problems in emergencies, though panics will not produce such serious results and escape from burning districts is easier.

The Santa Barbara earthquake proved that under favorable circumstances it is possible for a smaller city to undergo a severe shaking without a fire. Of course in this case the climate was favorable and individual heroism was a factor, in that an employee of the power company shut off the flow of current at considerable risk to himself. The outstanding lesson was that in a region where earthquakes may be expected from past history, preparation for the earthquake risk is absolutely essential. Investigation proved that if buildings had been properly constructed, even partial destruction of a dam and a severe shaking of the main business street would have caused no serious damage. On the same street there are buildings which are undamaged, slightly damaged, severely damaged, and entirely thrown down. Yet the total area is so small that all must have been subjected to practically the same stresses. The differences in construction details and the care taken in them is open to the light of the day.

EARTHQUAKE PERIL IN A THINLY SETTLED REGION.

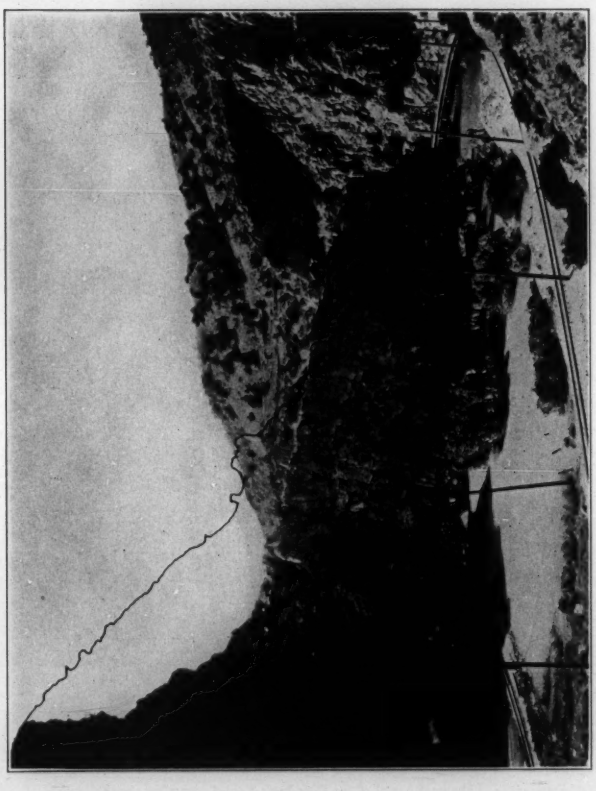
We now consider the case between the last and that of the region where earthquakes ordinarily have no important effect on man. This is the thinly settled mountain section of the West where the Montana earthquake occurred. Even in this case, where little damage was done in any towns beyond shaking

FIG. 4.



Photograph made in 1910, showing the appearance of the Deer Park (Mont.) Tunnel before the earthquake of June 27, 1925.
(Photo by Olsen, Three Forks, Mont.)

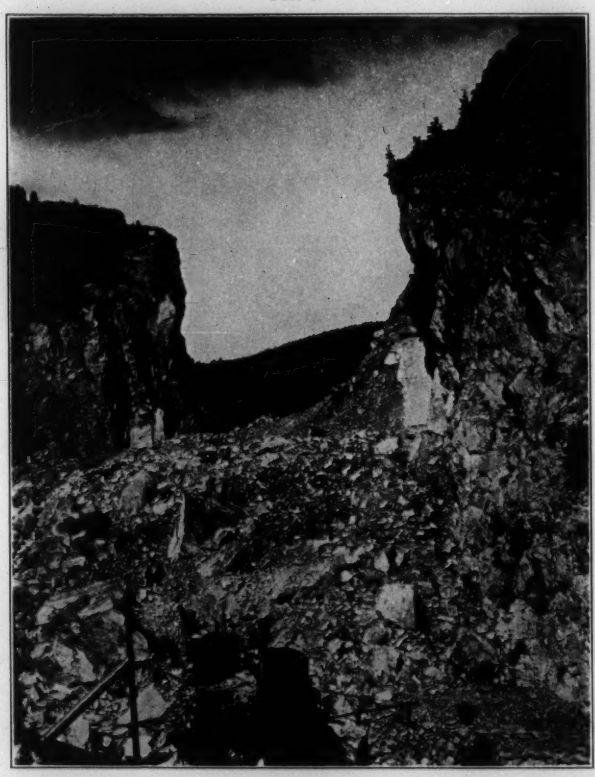
FIG. 5.



Same view as Fig. 4, after the earthquake. Black line indicates skyline before the earthquake.
(Photo by Olsen.)

down cornices of buildings, a grave disaster nearly occurred. About 6:00 P.M., on June 28, 1925, the *Olympian*, a fast train of the Chicago, Milwaukee and St. Paul Railroad Company, was

FIG. 6.



Appearance of the west portal of the Deer Park Tunnel soon after the earthquake.
(Photo by Olsen.)

proceeding with 350 passengers through Montana. Not a passenger gave thought to any danger and even the most timid had no fear beyond a train wreck. East of Lombard, at a small station

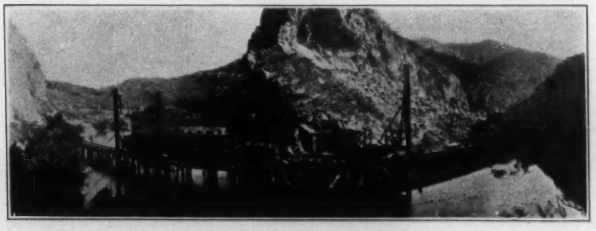
called Dear Park, the track followed a narrow canyon. At one place it was so narrow that a short tunnel was found necessary. Adjacent to the tunnel there was a high cliff overhanging the railroad. It was apparently of solid rock and to all indications

FIG. 7.

Portal of the Deer Park Tunnel blocked by the slide caused by the earthquake. (Photo by Olsen.)

quite safe. (Fig. 4.) Not even a seismologist anticipated an earthquake in this region. I have been informed that the Dominion Observatory experts at Ottawa, Canada, could scarcely believe

FIG. 8.



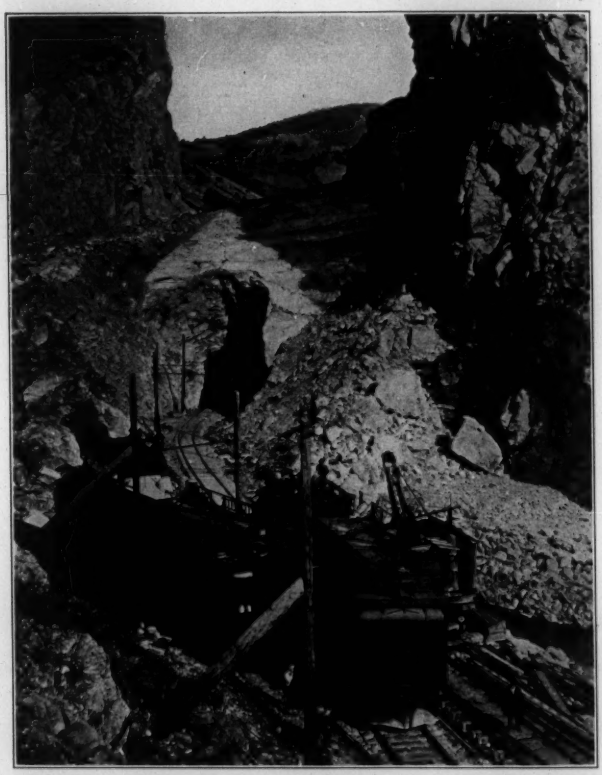
Repair work at Deer Park slide. (Photo by Olsen.)

that their instruments were not deceiving them when they located the earthquake in Montana.

Sixty-eight seconds after the train passed through the tunnel a large part of the cliff came down, with a great roar, filling the

end of the tunnel, deeply burying the track, and closing the canyon. Occurring a few seconds earlier, it would have buried the train

FIG. 9.



West portal of the Deer Park Tunnel on the day when the main line was again put into service.

(Photo by Olsen.)

from sight, and no living being would have escaped. (Figs. 5, 6 and 7.) The damming caused a lake to form, which in a few days was twenty-four feet deep. It was held at this level by

regulating the flow at the obstruction. In order to repair the disaster, it was necessary to place a trestle in the lake and carry on excavation work for a long period. The total cost to the railroad company was $1,500,000. (Figs. 8 and 9.)

This shows what may happen in a very thinly settled country, but one which our transcontinental trains must traverse. This earthquake, while relatively deep and shaking a large area, rather

FIG. 10.

Cracks opened in surface of Old Yellowstone Trail at Three Forks, Mont., during the earthquake of June 27, 1925.

than a small region with especial intensity, as at Santa Barbara, would have done very great damage in a region with many cities. In one village wide cracks opened in the roadway. This caused no special harm, but would have been a very serious matter in the centre of a large city. (Fig. 10.)

PERIL OF UNEXPECTED EARTHQUAKES.

I have stated that this earthquake was not expected by seismologists. It appears that we have had several unexpected earthquakes in the United States and this fact is no reflection on the seismologists. Statistics plainly show that the vast majority of earthquakes and nearly all the more severe ones occur beneath

the sea, especially along the great ocean troughs or foredeeps, in other places at sea where there are sudden changes in slope, and near the shores. There are some in the interior of the continents or in places of no slope, but in general in plain or plateau areas there are very few, nor are they common in very old geological formations.

However, in North America, in addition to normal activity in earthquake regions along the Pacific Coast, at various places from Alaska to Central America, both on shore and beneath the adjacent waters, there has been a number of severe earthquakes in regions of flat surface in an old geological formation. Outstanding examples include the St. Lawrence Valley earthquakes; that at Charleston, S. C., which geologists and seismologists are still trying to explain; and the 1811–1812 earthquake at New Madrid, Mo., in the Mississippi Valley, one of the great tremblers of history.

These earthquakes were distinctly unusual both in locality and high intensity at long intervals and this type needs special consideration. A severe earthquake in an unexpected place at very long intervals presents a more difficult problem than a series of earthquakes in a seismic region.

It is therefore necessary, in addition to local investigations, such as are being made in California at the present time, to have an adequate country-wide system of investigation in which the government must necessarily take an important part directly and in coördinating other activities.

SUMMARY OF SITUATION REGARDING EARTHQUAKE PERIL.

Let us summarize the situation as brought out before considering what science may do.

Earthquake activity is practically the same as it has been throughout historic time.

The peril to mankind has, however, greatly increased because of increased density of population and complexity of structures including underground structures.

Mental attitude has been a factor in increasing the danger, both in regard to panics in cities and in the mental inertia which has prevented progress.

The increasing peril has been greatest in large cities and steadily decreasing with lessening density of population. Increase

has been negligible in deserts and under the sea, except for tidal waves near seaports.

In North America we have had an exceptional number of severe earthquakes in regions believed exempt, with apparently long intervals between them. This makes country-wide study exceptionally important, in addition to detailed investigation of local seismic regions.

WHAT CAN SCIENCE DO?

What can science do about the earthquake peril?

It can collect accurate information about earthquakes.

It can map the earthquakes and can usually associate them with weak places in the earth's crust.

It can therefore point out the places where earthquakes are likely to occur, their probable severity and frequency.

It can give the engineer and architect the conditions which their structures must meet, and aid in designing the structures.

It can give the property owner and the insurance company a basis for proper earthquake insurance.

It can do these things, now, but nothing is more certain than when the work on these problems is adequately undertaken that undreamed of possibilities in meeting earthquake peril will appear.

EARTHQUAKE CENSUS.

An earthquake census should include certain facts beyond the bare chronology. It should answer the questions: When? Where? How intense? How deep? What area was affected? How much damage was done? What was the geological formation?

NON-INSTRUMENTAL REPORTS.

In a great earthquake it may take a volume to answer all these questions, but ordinarily it can be done in a catalogue covering all earthquakes for a definite period. The information must be collected by non-instrumental and instrumental methods, both of which are essential. While instruments give more exact and dependable information than the most careful observers, they have their limitations. They must necessarily be few in any region while observers are scattered everywhere. There are, however, many difficulties in regard to non-instrumental reports and sometimes seismologists in despair are almost ready to give up using them. It is daily proved in court that witnesses are not

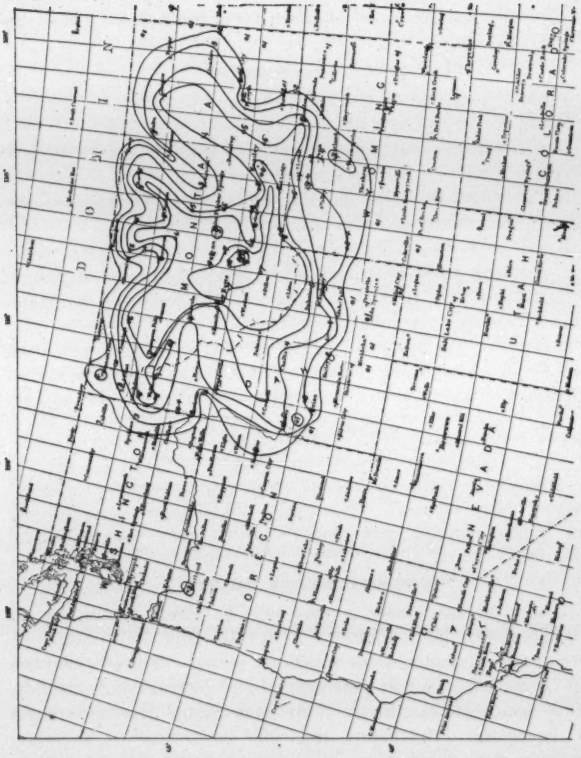


FIG. 11.

Isoseismal lines for the Montana earthquake of June 27, 1925. These lines as drawn are based upon non-instrumental reports collected by the Coast and Geodetic Survey. The number and distribution of the reports were inadequate for the satisfactory determination of the lines.

FIG. 12.

Form 639

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
E. LESTER JONES, Director

EARTHQUAKE REPORT

(Mail to Director, United States Coast and Geodetic Survey, Washington, D. C.)

IMPORTANT.—Answer questions in your own words or by writing or underscoring appropriate words. If necessary, use blank space at end of report for additional information. When a report is requested on a particular earthquake, the form should be returned even though the earthquake was not observed being sure to answer questions in I, II, and III. Newspaper clippings and photographic prints are very desirable.

I. Date of earthquake..... (Or NOT OBSERVED) Time (railroad)..... A. M. / P. M.

II. Name and address of observer.....

.....
(Include title of observer or institution)

III Location and occupation of observer when earthquake occurred.

1. In.....section of.....
(N., NE., central, etc.) (City, town, county, State)

.....on.....ground.
(In mountains, hills, valley, on plain) (Made, sandy, rocky, etc.)

2. Outside.....
(Riding, walking, sitting, lying down, sleeping, etc.)

3. Inside.....building
(Old, new) (Wood, brick, reinforced concrete, stone, etc.)

.....stories high, ...constructed.
(1, 2, 3, etc.) (Well, poorly)

Observer on.....floor, ...
(1, 2, 3, etc.) (Walking, sitting, lying down, sleeping, etc.)

IV. Character of ground movement:

1. Earthquake was felt by..... By observer?.....
(One, several, many, proportion of population) (Yes, no)

2. Number of shocks..... Onset.....
(Give time of each shock) (Gradual, rapid, abrupt)

3. Character of felt motion.....
(Trembling, bumping, rocking, swaying, etc.—give direction)

4. Did cracks appear in ground?.....
(Yes, no—give location and description)

5. Did land slides occur?.....
(Yes, no—give location and description)

6. Were tidal disturbances observed by anyone?.....
(Yes, no—give description)

V. Sounds:

1. *Surface* sounds due to creaking of buildings, rattling of loose objects, etc. heard by.....

..... By observer?.....
(One, several, many, proportion of population) (Yes, no)

2. *Subterranean* or earth sounds heard by..... By observer?.....
(One, several, many, proportion of population) (Yes, no)

2a. Subterranean sounds occurred.....beginning of earthquake.
(Before, at, after—give time interval)

2b. Character of sounds.....
(Faint, moderately loud—cracking, rattling, bumping, scraping, thunderous, roaring, whistling, etc.—describe fully)

3. Were any bells rung as a result of the earthquake?.....
(Yes, no—describe)

11—8000

FIG. 12.—Continued.

VI. Visible effects and damage:

1. Disturbed objects were observed by..... By observer?.....
(One, several, many, proportion of population) (Yes, no)

2. Was there any visible swaying of buildings or trees?.....
(Yes, no—describe)

3. Damage to buildings.....
(None, slight, considerable, severe)

3a. Damage to light structural parts such as chimneys, tile roofs, ornaments, etc.....
(Give extent and character of damage)

3b. Walls cracked.....
(Number—general direction of most badly cracked walls)

3c. Buildings partially damaged or destroyed.....

.....
(Number—well or poorly constructed—wood, brick, reinforced concrete, etc.)

4. Direction taken by fallen objects such as chimneys, monuments, etc.....

.....
(N., NE., E., etc.—no definite direction observed—give details if possible)

5. Damage to water mains, rails, bridges, structural foundations, cables, etc.....

.....
(Describe fully, giving directions of damaged objects such as rails and cables)

6. Effects on objects inside of buildings:

6a. Objects observed swinging or displaced.....

.....
(Chairs, tables, beds, pictures, chandeliers, doors, water in open containers, etc.—give directions in which objects swung or moved—give direction of walls on which objects were displaced the greatest amount—describe as fully as possible using additional space if necessary)

6b. Plaster on walls.....
(Not disturbed, cracked, broken, thrown down)

6c. Pendulum clocks stopped.....
(Give time of stopping—direction in which pendulum swung—approximate length of stopped pendulum. Give similar information about other pendulum clocks which did not stop)

VII. Effects on population.....
(Few doubtful or positive of ground movement—few or many alarmed—general alarm—few or many panic stricken—general panic—other details)

ADDITIONAL INFORMATION

(Other sheets of descriptive matter may be attached to this report)

11—8000

Front and reverse sides of the form for non-instrumental reports furnished by the Coast and Geodetic Survey to volunteer observers.

able to tell their experiences with accuracy and certainty, and this is perhaps more true under the stress of earthquakes. Newspaper reports are sometimes governed by desire for sensationalism and sometimes by desire to suppress facts, though at present most of them are fairly good. It is found that if we receive enough reports of the right kind and take into consideration the fact that the actual conditions observed vary from place to place, we are able to arrive at fairly consistent interpretations. (Fig. 11.) The Coast and Geodetic Survey is at present studying this problem and hopes to arrive at a better solution in the near future. These reports should answer in part at least the above questions: Approximately when? Where? How intense? What area was affected, that is, actually shaken? What damage was done? The geological questions have to be studied by geologists. (Fig. 12.)

The usual reports are of value only if the region is thickly settled. If thinly settled the reports are too widely spaced and, generally speaking, the number of intelligent observers is considerably less.

INSTRUMENTAL REPORTS.

In most scientific studies we come to the problem of instruments and most of the progress in seismology has been connected with the development of instruments. Up to the recent past Europe has fully appreciated this, while the United States has in a large measure ignored it. We became interested in the subject not long after it was taken up in Japan and Europe, but until recently have contributed almost nothing to instrumental development, the sole exception being some early work of the United States Weather Bureau. There is difficult mathematics underlying not only the theory of instruments, but also the transmission of waves through the earth, and progress cannot be made in the latter study without the best instruments carefully operated. Nearly all of the important advances in Europe have been made during the last twenty-five years and we have been operating seismographs for a longer time than this.

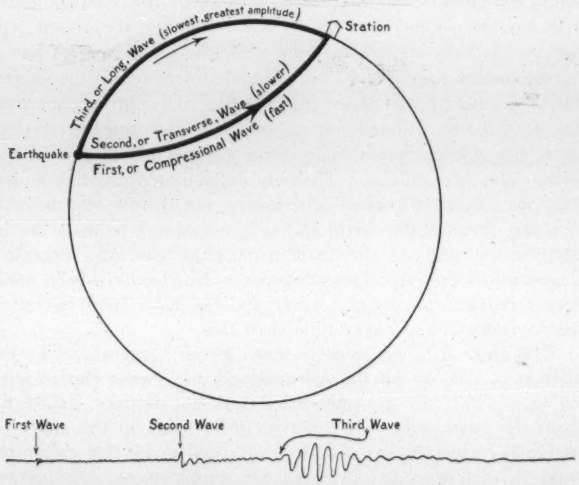
The publication of accurate seismograph observations by the British Association for the Advancement of Science started with the year 1899, but the publication was not actually issued till about ten years later, when the progress made in the study of earthquake-wave transmission had advanced so far that epicentres could be determined. In 1913 the tables were still further improved and this process is still going on. In North America, Dr. Otto Klots, of the Dominion Observatory, Ottawa, Canada, took an important part in this work. It seems that it is time for the United States to take its proper place in all these operations and there are signs that the needed awakening is approaching.

Earthquake epicentres are obtained in a rather simple manner. We have the primary and secondary waves recorded on the seismograph and the difference in the time of their arrival gives the distance from the seismograph to the point where the earthquake occurred. The distance is obtained from the tables just mentioned. Knowing the distance from a number of stations, we swing arcs from each of the stations and the earthquake occurred at the intersection of the arcs. The actual practice is more

complicated and there are numerous difficulties, but no important departure from the principle described. (Figs. 13 and 14.)

Up to the present time we have had few good instruments in this country, especially if judged by present-day European standards. Georgetown University has the best instrumental equipment in the United States and has recently improved it by the

FIG. 13.



Difference in times of arrival of first and second waves, gives distance from earthquake to station.

Schematic representation of the paths of the three principal seismic waves from the earthquake to a distant station and the general appearance of the seismogram produced at this station by the waves.

addition of a vertical instrument. Chicago University and the Coast and Geodetic Survey Magnetic Observatory at Honolulu have standard British instruments. There are a few German instruments of good types scattered through the country. Many of the observatories, including three observatories of the Coast and Geodetic Survey, have German types, standard about twenty-five years ago, but now considered obsolete, and for which no spare parts can be obtained because the manufacturers have gone out of business. (Fig. 15.)

A new seismograph known as the Wood-Anderson torsion

seismograph has been developed in California primarily for investigation of nearby earthquakes. This has also been adapted for recording distant earthquakes. The Coast and Geodetic Survey Magnetic Observatory at Tucson, Ariz., is substituting this

FIG. 14.

With known distances the seismologist by means of a tape swings arcs from several stations. Their intersection tells him the position of the earthquake.

instrument for its worn-out, obsolete one. A similar installation is planned for St. Louis University. (Fig. 16.)

Good instruments give records which make the following things possible at present: Determination of epicentre; time of

occurrence; intensity of earth movement at seismograph; and some idea of depth of focus or place where the earthquake actually occurred. It is also possible to reverse the problem of determining distance and time of origin for any station. The epicentre and time of origin are determined either from nearby stations or in some cases from knowledge that the area of maximum damage was very restricted. With known epicentre and time of origin

FIG. 15.

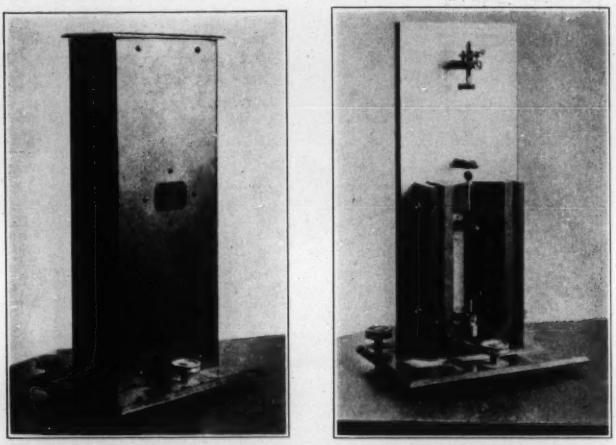
Bosch-Omori horizontal pendulum seismograph. This instrument was introduced about thirty years ago and has been quite useful in its day. It is entirely inadequate, however, for the needs of modern seismology.

the velocity of wave transmission to any station which has a good record of the earthquake may be readily computed.

Even if our instruments are of the best type, most of them are horizontal seismographs and do not respond to vertical waves. In many cases most of the energy arriving is from a direction nearer to the vertical than to the horizontal. As stated there is a vertical instrument at Georgetown and there should be others elsewhere. The greatest advance would result if a vertical instrument, bearing the same relation to European vertical seismographs that the Wood-Anderson bears to most European horizontal seismographs, were developed. (Figs. 17 and 18.)

There is another phase to this development which is being emphasized in the Wood-Anderson instrument. Until the World War little attention had been paid to the development of apparatus to turn recording drums at constant speed. The various seismographs were designed with great attention to detail and then some of the benefit was lost because of the uneven turning rate of the recording apparatus. The recording arrangement for the

FIG. 16.



The modern Wood-Anderson horizontal component seismograph. The two views show the instrument with cover in place and with cover removed. The recording apparatus is not shown.

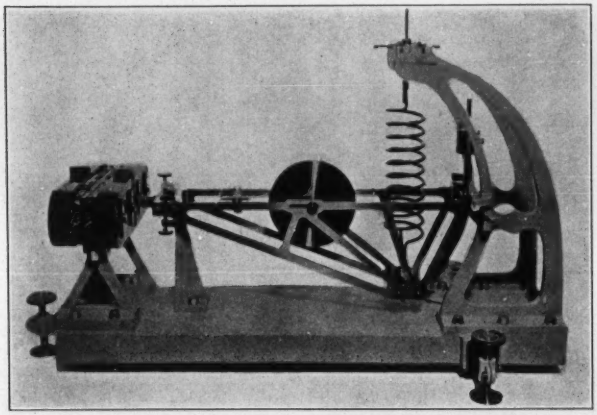
Wood-Anderson seismograph takes advantage of the latest method of securing uniform rotation at not too great cost. When this development has been carried a little further and specially suited for recording distant earthquakes, and the instruments become available, there will be a great advance in seismology in the United States.

TRANSMISSION OF EARTHQUAKE WAVES.

Tables of transmission of velocity of earthquake waves have been mentioned. Dr. James B. MacElwane, St. Louis University, Director of the Jesuit Seismological Association, is preparing

tables which permit many recently identified phases of the earthquake record to be utilized so that more information will be obtained from each record. Unless, however, the records are obtained from good instruments there is little gain over the old tables, which give only the principal phases. These extra phases or series of waves arriving through the earth and recorded on the seismogram have to be explained. This brings out an inter-

FIG. 17.



Galitzin vertical component seismograph.

esting feature of the work, that is, that here we have some definite knowledge of the probable constitution of the earth. The waves which go through the earth are reflected in various ways, not only at the surface but from reflecting surfaces at various depths. The evidence appears to be overwhelmingly in favor of reflecting layers at depths of 60 kilometres and 2900 kilometres. Such investigation, to account for the various waves utilized in the tables mentioned, requires a vast amount of study.

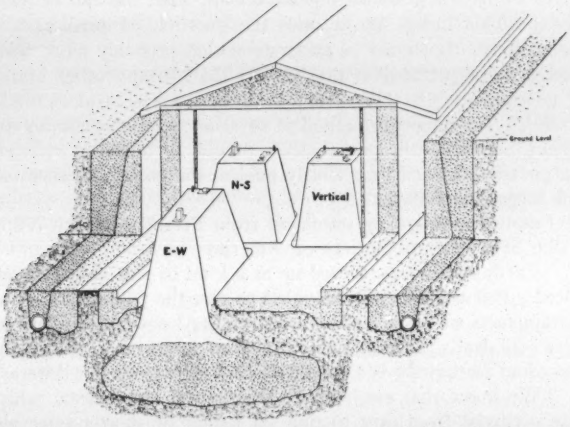
Most of the theory assumes the same mean transmission velocities for a given distance under all conditions. This is, of course, not the case, although the average values given in the tables give fairly good result. The records at the Honolulu Magnetic Observatory in Mid-Pacific show departures from the average values

not yet fully explained, and this will be made the subject of a special investigation in the near future.

INTENSITY OF GROUND MOVEMENT.

The intensity of ground movement is an important factor. No means have as yet been devised to measure in a satisfactory manner the intensity near the epicentre of a strong earthquake.

FIG. 18.



Schematic representation of a modern seismograph house, containing Wood-Anderson E-W and N-S horizontal component instruments and Galitzin vertical component instrument.

At a distance the intensity can be determined, provided we have instruments of modern type so that the record corresponds to the actual ground movement.

DEPTH OF EARTHQUAKE.

The effect of an earthquake varies greatly with the depth below the surface at which it occurs. The determination of this depth has so far proved one of the most difficult problems in seismology. Several methods have been devised, based on the direction at which the waves emerge from the earth or upon the relative times of arrival of waves at nearby stations, but the different methods give different results and none has as yet proved entirely satisfactory.

The result of complete study of instrumental results furnishes an important part of our earthquake census. This is usually given in the form of a catalogue, but it can also be given in the form of a map. The great value of such a map lies in the possibility of associating earthquakes directly with geological formations in which they occur.

EARTHQUAKE PREDICTION.

If we have a good earthquake census, what use can be made of it? This brings up at once the question of prediction of earthquakes. It should be understood that probably more fakes have been perpetrated in this subject than in any other branch of geophysics. At the present time there are several examples of this. The favorite method is to select an active earthquake region, figure out the probabilities, predict by allowing sufficient margin of time, and then widely publish the occasional successes and forget the failures.

I quote the following statement from President Bailey Willis, of the Seismological Society of America:

"Earthquake news, served up as a kind of side dish, is overspiced. It is time for seismologists to give the public plain food. Certain facts we know; others we think we know; still others we infer confidently; others doubtfully; then we guess. The prediction of an earthquake is a guess, which I prefer to call a forecast.

"We know that earthquakes are natural phenomena, which have occurred from time to time, at longer or shorter intervals, with greater or less violence, but unequally as regards time intervals and intensities in different countries.

"If earthquakes were like comets they would return at definite intervals. But they do not resemble comets in any respect whatever. Rather are they like storms, an effect of concentrated energy; gathered in the one case in the air and reaching a crisis at frequent intervals; in the other case, gathered in the earth's crust and rising to a critical state at longer intervals. That much we know regarding their periodicity and we can say with confidence that the farther we are from the last great shock, the nearer we are to the next one."

While science is not at the present time, and may never be, able to predict earthquakes accurately in time and place, this does not mean that it can accomplish nothing.

EARTHQUAKE EXPECTANCY.

The earthquake census and maps supplemented by the necessary geological investigation will in most cases indicate the faults or lines of weakness where earthquakes are likely to occur. For any given region this information enables us to get some idea of the probable place, frequency and intensity of earthquakes. At the present time there are few places in the United States where this information is satisfactory. Instrumental reports were negligible before 1900 and non-instrumental reports are more difficult to appraise than those of the present day. Obviously one of the important present needs is complete and accurate information so that the census and maps may serve the purpose of furnishing the best possible gauge of earthquake expectancy.

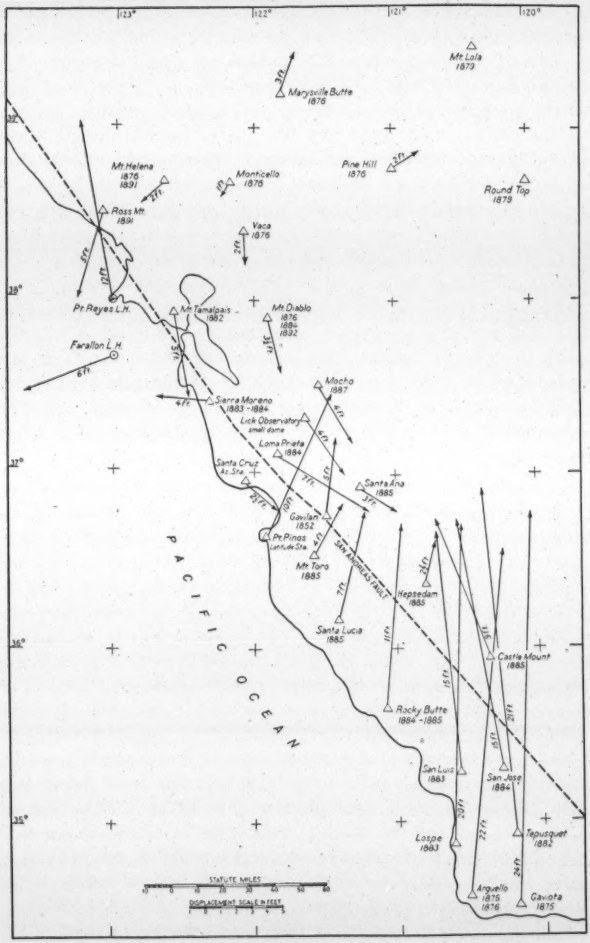
Accurate regional information of the type that has been described is the chief present need of the insurance companies in appraising earthquake risks. Rates based on anything but probable earthquake occurrence have no justification as they are virtually certain to be either too high to be retained when no earthquakes are occurring or too low to safeguard the insurance companies.

MEASUREMENT OF CRUSTAL CREEP AS INDICATION OF STRAIN.

In the matter of determination of earthquake probability by scientific methods, one of the most important has not yet been mentioned. It can, generally speaking, be applied only in a limited region. This is the execution of geodetic surveys from time to time to determine whether the geographical positions and elevations of points have changed. In most regions it is assumed that points remain unchanged except when geological periods are considered, but this is not true in earthquake regions. The changes could actually be seen in parts of California after the earthquake in 1906 and were measured by geodetic methods. Changes are specially evident when there is movement in opposite directions on the two sides of a fault. It has been found that even without an earthquake there may be crustal creep, that is, shifting of part of the earth's crust with reference to another part. Such creep is usually considered evidence of increasing strain which is likely to result in a sudden release accompanied by an earthquake. (Fig. 19.)

During the last four years there has been going on in California a geodetic survey made entirely for a study of this question.

FIG. 19.



Discrepancies between old (1875 to 1892) and new (1922 and 1923) triangulations, Northern California.

The differences in geographic positions, as computed from the early (1875 to 1892) and from the recent (1922 and 1923) ones, are shown by arrows. The direction of each arrow indicates the direction of shift in geographic position during the interval between the two sets of observations. A part of the change in geographic positions is due to unavoidable accidental errors in making the angle observations, but most of the changes seem to indicate actual earth movements. In the computations it was assumed that no earth movements had occurred at stations Mount Lola and Round Top, on the Sierras. Those two stations form the base for the computation of the new geographic positions of all the other stations shown on the sketch.

The preliminary results indicated a very considerable change in the vicinity of Point Conception and the significance of this change is the subject of much speculation. The present survey has great value in that it connects stations in the disturbed region to the unchanged region of the Sierras.

Such geodetic surveys will hereafter be considered a necessary preliminary to all regional investigations and they will have to be repeated from time to time during an investigation.

There is some indication that acoustic methods may have some value in determining increase of strain which is likely to be released by an earthquake. Such instruments make it possible to record sounds as well as to hear them and such records may prove to have significance.

To indicate how difficult it would be to make accurate predictions in time, it seems to be established beyond reasonable doubt that the conditions may be ripe for the occurrence of the earthquake and yet it will hold off until some special condition suddenly arises to act as a trigger in setting it off. Such an occasion may be an unusually great range in tide or a sudden change of barometric pressure. We therefore not only have to deal with strains in the earth and their release, but with the manner in which the release occurs.

EARTHQUAKE CENSUS INDICATE WHERE AND WHAT PRECAUTIONS ARE NEEDED.

There are few parts of the earth which are entirely free from earthquakes, but in many regions the probability is so low that no precautions except good, well-enforced building codes are necessary. Then we have regions in which great earthquakes have occurred in the past, but of which we do not know the present condition. Scientific study is specially needed in such regions to find out what should be done. There are also known earthquake regions where the most needed information is the probable interval of recurrence of moderately severe earthquakes, and the maximum likely effects. In such regions it is usually possible to arrive at an appraisal of conditions to determine logical precautions.

If the records show the probability of a severe shock in a given region, the fact should be recognized and an effort made to meet the situation. Even if little or nothing can be done about existing buildings and other structures, future constructions should be controlled in the interest of prevention of damage by earthquake.

As time goes on and the various scientific studies which have been outlined begin to furnish results, the basis for action will become better and better and eventually it will be considered criminal neglect for a community exposed to earthquake danger to fail to make adequate provision to meet it. When this time arrives earthquakes will be treated with respect, but not feared or ignored as at present. The situation will be somewhat analogous to the change at sea. The Romans avoided winter voyages in the Mediterranean where winter voyages are now a commonplace, though weather conditions have remained practically unchanged.

With the best possible information as to probable occurrence of earthquakes and definite knowledge of the effect on structures, architects and engineers may proceed to design safe structures. Rigid building codes are needed, as nothing is surer than that an earthquake will pick out the weak places in design and will expose poor work. It has been proposed to erect special buildings in earthquake regions and study the effects. Engineers will have the problem of placing underground structures in best relations to faults. I do not intend to go into this subject in detail, but will give a number of references to descriptions of what is being done:

Bulletin Allied Architects Association of Los Angeles, Santa Barbara Earthquake Number, Vol. I, No. 10, August 1, 1925.

"Earthquake Expectancy in California," Henry D. Dewell, *Engineering News-Record*, Vol. 96, No. 3, January 21, 1926.

"Building in Earthquake and Tornado Regions," Robins Fleming, *Engineering* (London), January 22, 1926.

The most severe handicap of all those at work in the subject is lack of complete and coördinated knowledge. If all the activities can be made effective there is great hope for the future solution of the various problems, insofar as they can be solved.

NEED FOR COÖRDINATION OF EARTHQUAKE INVESTIGATIONS.

This means careful coördination of all activities with special effort to see that none of the essential activities is overlooked and that there is no important overlap of activity. The greater part of the work must be done by private initiative, but it has been demonstrated that it must be done by organizations and not by individuals working alone. A fine example is found in California where the Advisory Committee of Seismology of the Carnegie Institution of Washington has arranged for the success-

ful coöperation of several branches of the Federal Government, the California universities, and business organizations, so that much of the activity is financed locally while part of it is national, and yet all is well coördinated. The Jesuit Seismological Association has recently been organized, with headquarters at St. Louis, to coördinate the activities of its important group of stations and is contemplating a special investigation in the region of the great New Madrid earthquake of 1811–1812. In New England the Engineering Economics Foundation is using the earthquake as an example of the type of emergency for which cities should be organized. The Seismological Society of America has an important duty in bringing together people interested in the subject, but from widely varying viewpoints.

The work of this society is becoming more effective in the East through the formation of an Eastern Section which is now in progress. The plans include an annual meeting which will cover the range of interests concerned with earthquakes, the first of which is to be held in Washington on May 1st. It will also issue a section bulletin which will carry references to what is being done to meet the earthquake peril. It appears that this section is going to provide a most useful means of securing coöperation in earthquake work and in guarding against too great loss of activity in the periods of quiet which necessarily come between the earthquakes which concern us.

PLACE OF THE GOVERNMENT IN SEISMOLOGICAL WORK.

As Director of the Bureau charged with carrying on this work for the government, it seems proper for me to indicate my views as to the proper function of the government in this field. My view is that it should encourage all proper activities and render assistance to those in need of it in any suitable way; it should take an active part in the coördination of activities; it should carefully avoid duplicating other activities; it should take the principal share in securing non-instrumental reports for the reasons that people do not wish to be asked for this information by more than one agency, and that they are less likely to refuse information since they feel that use of it will be impartial. In this connection I wish to call attention to the fact that reports from the United States Weather Bureau have been continued since that bureau ceased to be charged with the work and have proved inval-

uable during the earthquake activity of the past year. The Coast and Geodetic Survey should have the best installations at its observatories, which are in general placed most fortunately in important earthquake regions where they conflict with no other activity. It should have a small group of experts who will be available for work in the field in studying earthquake effects, in standardizing instrumental work, or for office studies of the subject. The publication of earthquake information, which has been started, should become more complete and be published at regular intervals. The government should keep in close touch with all efforts to solve this problem, even though not directly in line with its special activities. Each earthquake causing change in the surface conditions should be studied in detail by the United States Geological Survey.

CONCLUSION.

In this great earth science, seismology, we have to a remarkable degree the combination of an immense number of scientific problems which must be solved in order to achieve the practical applications so necessary for the welfare of mankind. An able editorial in the *Saturday Evening Post* of January 16, 1926, expresses the situation as follows: "Scientific research on this subject is in its beginnings, but tremendous strides are almost sure to be made in the next few years. The economic and practical forms of preparation are just as essential as the scientific. The public mind must become receptive to sane measures of precaution. Organizations of architects and engineers are approaching the strictly economic aspects of seismology with energy and sincerity of purpose. Their investigations already show that damage in a large measure comes not so much from the inherent weakness of materials to withstand the strain, as from the frail humanity which seeks to squeeze the last dollar out of an investment.

"Earthquakes may in time accomplish one great service. They may teach even the most mercenary, if enough of these shocks come along, that good workmanship pays. For the earthquake respects only honesty of construction."

I can only add that the same honesty must be applied to the study of all the problems and to acceptance by the public of the facts that are brought out. I feel certain that the awakening is nation-wide, serious and permanent, and the effect will assure the greater protection and security of life and property.

THE KENNELLY-HEAVISIDE LAYER AND RADIO-WAVE PROPAGATION.*

BY

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A THEORY, in many respects quantitative, of the manner in which radio waves pass around the earth is described in the present paper. The regions of the upper atmosphere, rich in electrons, known as the Kennelly-Heaviside layer, play an important rôle. From the theory many numerical facts of the propagation, distortion and polarization of the radio waves receive adequate explanation. The earlier portions of this paper are based on a paper by Taylor and Hulburt,[1] the latter parts dealing with the polarization of the received wave are new.

In 1901 Marconi, in his transatlantic signalling experiments, demonstrated for the first time that the wireless rays could bend around the bulge of the earth. Lord Rayleigh immediately raised the question as to how this could be. In answer Kennelly [2] and Heaviside [3] independently suggested the possibility of the downward refraction of the rays by the ions of the atmosphere. No test of this idea was possible, for quantitative experimental measurements were lacking at that time. Such observations were not forthcoming until 1910 and 1913, when the United States Navy, under the direction of Austin,[4] measured the variation of the strength of the received signal as the distance from the transmitting station was increased for radio waves longer than 500 metres. The results are usually expressed by the well-known Austin-Cohen formula, which showed in particular that the intensity of the received wave fell off faster with the distance from the source than would be required by a simple inverse square law.

* Delivered Tuesday afternoon, March 9, 1926, in the lecture hall of the Institute.

[1] TAYLOR and HULBURT, *Phys. Rev.*, 27, 189 (1926).

[2] KENNELLY, *Elec. World and Eng.*, p. 473 (Mar. 15, 1902).

[3] HEAVISIDE, "Encyclopedia Britannica," Tenth Edition, Ninth Volume (No. XXXIII), p. 215 (Dec. 19, 1902).

[4] AUSTIN, *Bull. Bur. Stand.*, 7, 317 (1911).

The question was then asked, could not the electric waves reach distant points around the earth in sufficient intensity by diffraction? This possibility was finally disposed of by the mathematical researches of Nicholson,[5] Love,[6] Van der Pol,[7] Macdonald,[8] Watson[9] and others. It was concluded that a simple theory of diffraction of the waves around an earth of finite, or infinite, conductivity immersed in a limitless dielectric yielded an intensity decrement factor very much greater than the experimental factor of the Austin-Cohen formula. In order to obtain agreement with observations, the presence of converging waves was necessary, which meant that a portion, at least, of the waves must be reflected or refracted downward from the ionized upper reaches of the atmosphere. This was in strong support of the Kennelly-Heaviside conception which just at that time had been given a more definite formulation by Eccles.[10] Eccles assumed an upper layer so intensely ionized as to reflect the rays without penetration, combined with an ionization of the middle atmosphere which bent them, and in his treatment dealt only with the motions of the heavy ions. It has remained for Larmor [11] to sketch a theory of refraction due largely to the free electrons. These were shown to be of such long free path as to exert a negligible absorption on the waves passing through them. Being lighter than the ions of Eccles, only comparatively few electrons were necessary to produce sufficient bending of the rays.

At the end of the year 1924 it appeared that a reasonable and adequate theory of radio-wave propagation had been rounded out, as yet qualitative to be sure, but requiring only obvious measurements to be placed on a quantitative basis. At this satisfactory stage, as has often happened before, new phenomena made their appearance, which the theory was unable to cope with. Larmor's equations gave a refraction which decreased with the wave-length becoming small for waves below 60 metres, whereas

[5] NICHOLSON, *Phil. Mag.*, **22**, 157 (1910); **21**, 62 (1911).
[6] LOVE, *Phil. Trans. Roy. Soc.*, A, 215, 105.
[7] VAN DER POL, *Phil. Mag.*, **38**, 365 (1919).
[8] MACDONALD, *Proc. Roy. Soc.*, 71A, 251 (1903).
[9] WATSON, *Proc. Roy. Soc.*, 95A, 546 (1919).
[10] ECCLES, *Proc. Roy. Soc.*, 87A, 79 (1912).
[11] LARMOR, *Phil. Mag.*, **48**, 1025 (Dec., 1924).

the work of Reinartz [12] and Taylor [13] on the "skip distance" for waves below 60 metres immediately indicated a stronger refraction than for the long waves. Fortunately, at this time Appleton [14] pointed out that the free electrons would move in spiral paths at a specified frequency because of the magnetic field of the earth, and that perhaps peculiar effects would occur for waves near this frequency. This meant of course the introduction of a critical frequency term into the refraction equation, which produced exactly the modification required, *i.e.*, it left Larmor's equations (which had neglected the magnetic field of the earth) approximately unchanged in the region of longer waves and brought the theory into agreement with the short wave data. From Appleton's suggestion it was immediately possible to apply the classical formulas of magneto-optics to the Kennelly-Heaviside layer.

THE DISPERSION OF THE KENNELLY-HEAVISIDE LAYER.

It is assumed that the regions of the Kennelly-Heaviside layer owe, in the main, their optical properties to the presence of the free equations, and in the equations the influence of the magnetic field of the earth is taken into account. The problem thus amounts to determining the dispersion formulas of a magnetized cloud of free electrons. We follow the classical electron theory of Lorentz,[15] and in application to the present problem assume no restoring force on the electrons due to the medium, no absorption, and no effect of the electrons on each other. The charge on the electron is denoted by e, its mass by m; N is the number of electrons per unit volume; c is the velocity of light in vacuum. The magnetic permeability of the medium is taken to be unity. All quantities are expressed in c.g.s.e.m. units.

Propagation Parallel to the Magnetic Field.—This case will apply approximately to north and south propagation. We denote the magnetic field by H and suppose it to be in the direction of the propagation of the radiation. The solutions [1] of the appropriate equations of motion of the electron yield two vibrations

[12] REINARTZ, "QST" 9, 9 (April, 1925).
[13] TAYLOR, *Proc. Inst. Rad. Eng.*, 13, 677 (Dec., 1925).
[14] APPLETON, *Proc. Phys. Soc. London*, 37, Part 2, p. 22D (Feb., 1925).
[15] H. A. LORENTZ, "The Theory of Electrons," Chap. IV (1916).

circularly polarized in opposite directions, whose refractive indices μ are given by the relations

$$\mu^2 = 1 - \frac{C\lambda^2}{1 - \lambda/\lambda_0}, \tag{1}$$

$$\mu^2 = 1 - \frac{C\lambda^2}{1 + \lambda/\lambda_0}, \tag{2}$$

where

$$C = Ne^2/\pi m \text{ and } \lambda_0 = 2\pi cm/He. \tag{3}$$

If the refraction is not great or the distance of propagation is small the wave remains coherent and the two circularly polarized components add to give in general an elliptically polarized wave. For equal intensities of the two components the resultant wave is plane polarized with the plane of polarization rotated from its original direction. If the two components are separated, by greater refraction or distance, each will proceed as a circularly polarized wave.

Propagation Perpendicular to the Magnetic Field.—In this case, which will refer approximately to east and west propagation, the initially plane-polarized wave is resolved in general into two component vibrations with electric vectors parallel and perpendicular to H, respectively. The solutions of the appropriate equations of motion of the electron yield refractive indices μ for the parallel and perpendicular cases, respectively,

$$\mu^2 = 1 - C\lambda^2, \tag{4}$$

$$\mu^2 = 1 - \frac{C\lambda^2}{1 - \lambda^2/\lambda_0^2(1 - C\lambda^2)}. \tag{5}$$

If the wave remains coherent the two plane vibrations unite to produce in general an elliptically polarized wave, but if the two components are separated, each will proceed as a plane-polarized wave. Equation (5) of course represents the propagation in the absence of a magnetic field as discussed by Larmor. It may be mentioned in passing, although no use is made of the fact here, that for the plane-polarized wave component of formula (5) the electrons describe ellipses whose planes are parallel to the direction of propagation of the wave and perpendicular to H. From one point of view these vibrations can not be said to be transversal. This peculiar instance was recognized long ago by Voigt. The case may be compared with the motion of the particles on the surface of deep-sea waves on water.

In the general case of propagation at an angle with the mag-

netic field, all four of the modes of vibration just discussed may occur in greater or less proportion, with the result that the wave, if coherent, will become elliptically polarized, the orientation of the axes and the eccentricity of the ellipse changing as the wave proceeds. If the refraction or distance of propagation is sufficiently great the various components may be separated from each other.

Taking the value of H for the earth's magnetic field to be 0.5 gauss, λ_0 from (3) comes out to be 214 metres, which is the value used for λ_0 throughout this paper.

To bring out the characters of the various dispersion formulas, the curves 1, 2, 4 and 5 have been plotted in Fig. 3 from equations (1), (2), (4) and (5), respectively, choosing $N = 3.95 \times 10^5$ electrons per c.c. In the region of wave-lengths less than 50 metres the curves do not differ greatly. With increase in λ all the curves of Fig. 3 descend to zero and μ becomes imaginary, remaining so for the longer waves in the case of curves 2 and 4. For curves 1 and 5, μ remains imaginary until wave-lengths λ_0 and $\lambda_0 \sqrt{1 - C\lambda^2}$ are reached, respectively. At these wave-lengths, called the "critical" wave-lengths, μ is $\sqrt{\pm\infty}$ and as λ is increased beyond them, μ descends from high positive values finally to low values again. As a matter of fact, the critical wave-length $\lambda_0 \sqrt{1 - C\lambda^2}$ appears to be of no physical importance, for, due to the presence of C in this expression, no wave can reach the region of electron density where this critical condition for the wave prevails.

Absorption in the Kennelly-Heaviside Layer.—Among various possible causes of absorption of energy from the electromagnetic wave by the upper reaches of the atmosphere, the most important would seem to arise from collisions between electrons and molecules. This would convert a portion of the energy of the wave into heat. Simple calculations, such as given by Larmor and by Nichols and Schelleng,[16] indicate that the probability of collision is small, so that absorption due to this cause is negligible, except in the region near the critical wave-length λ_0 and for very long waves outside of the usual radio range, which have a very slow oscillation. In lower regions of the atmosphere, where the density of molecules is greater, absorption due to collision might exist

[16] NICHOLS and SCHELLENG, *Bell Sys. Tech. J.*, 4, 215 (April, 1925).

even for shorter waves. If we assume that this type of absorption can be expressed as a frictional term in the equations of motion of the electron, which is no doubt permissible within limits, the dispersion formulas are all available in treatises on magneto-optics. For small absorption these differ from equations (1), (2), (4) and (5) by wholly inappreciable amounts for wave-lengths removed by, say, 30 metres from $\lambda_0 = 214$ metres. Near to this critical region the absorption term produces complex modifications. It is, however, justifiable to neglect absorption as long as the critical region is avoided; and we have been content to avoid this region because of its complexity and because the observations on these wave-lengths are mainly qualitative.

For a wave travelling near the earth, the matter of absorption is quite different. This has been discussed by Zenneck,[17] Sommerfeld and others who showed that the earth absorption may become very high for the shorter waves. The successful radio transmission to distances as great as halfway around the earth with waves below 90 metres proves that the attenuation is small, no matter to what cause it is attributed, and this combined with the pronounced earth absorption for the shorter waves leads forcibly to the conclusion that the waves must travel in the upper atmosphere and that the absorption in these regions is slight.

RANGE AND SKIP-DISTANCE DATA.

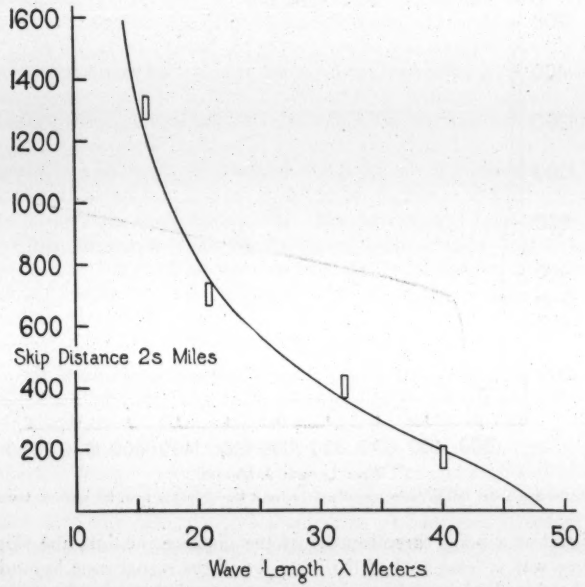
The observational data of interest in the present development are to be found in Taylor's Range Chart,[18] which presents in graphical form a summary of a large number of experimental observations on the transmission of radio waves of wave-lengths from 16 to 3000 metres over distances up to 10,000 miles. The experiments have been carried out during recent years by the Radio Division of the Naval Research Laboratory with the assistance of the American Radio Relay League and their co-workers in the foreign countries. On the chart, which is not reproduced here, are plotted the relative ranges of transmission of the various wave-lengths, as far as they have been investigated, reduced to a uniform condition, namely, 5 kilowatts in a normal transmitting antenna. The average ranges for day and night and for summer and winter are included.

From the chart certain new facts regarding the behavior of

[17] ZENNECK, "Wireless Telegraphy," 3rd Ed., p. 248 (1915).

the short waves stand out. It has been found that for wave-lengths shorter than 50 metres the intensity of the received signal decreased as the distance from the transmitter was increased, reaching a value too small to be observed at a distance of a hundred miles or so. With further increase of distance the

FIG. 1.

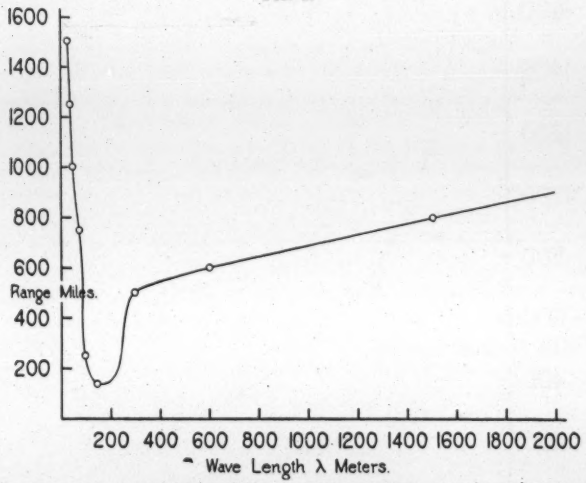


The skip distances average throughout a year, for full daylight conditions, as a function of wave-length.

received signal remained undetectable until a region was reached where the received signal became strong again, rising rapidly to a maximum and thereafter decreasing rather slowly. The distance from the transmitter to the far edge of the region of silence, which we may call the "skip distance," was found to increase rapidly as the wave-length decreased; for a specified wave-length it was longer at night than in the day and longer in winter than in summer. The skip zone was not very sharply defined of course, but

passed into the region of steady signals through a transition zone, sometimes called the "flicker" zone, where the signals were erratic and subject to violent fading. It may be emphasized that the skip zone was not merely a zone of uncertain signal reception, but a region where the signals were entirely absent for the most part; a conservative estimate would be that the intensity of the

FIG. 2.



The ranges, under full daylight conditions, averaged throughout a year, for uniform transmitting conditions, as a function of wave-length.

signal at a point three-fourths of the distance out into the skip zone was at least 10^{-4} of the intensity of the signal zone beyond. The skip distances, denoted by $2s$, averaged throughout a year, for full daylight conditions, for wave-lengths 16, 21, 32 and 40 metres, were 1300, 700, 400 and 175 miles, respectively. These are plotted as rectangles in Fig. 1. The values naturally can not claim great accuracy and may perhaps be in error by as much as a hundred miles. The skip distances at night are not yet known with precision. This is due perhaps to an insufficiency of data, but more probably to the fact that conditions at night are so erratic that even more extended observations would fix the distances only within wide limits. Present information indicates,

however, that the night skip distances are on a rough average two to four times the corresponding day values.

We regard these skip-distance phenomena as demonstrating forcibly that two portions of the transmitted wave may be differentiated, one which clings to the earth and decreases rapidly in intensity until it is lost, and the other which moves in an upward direction and returns to the earth after refraction, with little attenuation in the Kennelly-Heaviside layer.

In Fig. 2 are plotted the ranges, under full daylight condition, averaged throughout a year for uniform transmitting conditions, *i.e.*, 5 kilowatts in a normal transmitting antenna, against the corresponding wave-lengths. Although the physical basis of the curve is essentially composite, for each wave-length may be propagated in a characteristic manner, the pronounced minimum in the curve at about 200 metres is taken to suggest a critical region of dispersion or of absorption. The agreement of the position of the minimum with the calculated critical wave-length 214 metres is regarded as an experimental confirmation, none too direct, however, of the theoretical calculation given in an earlier paragraph.

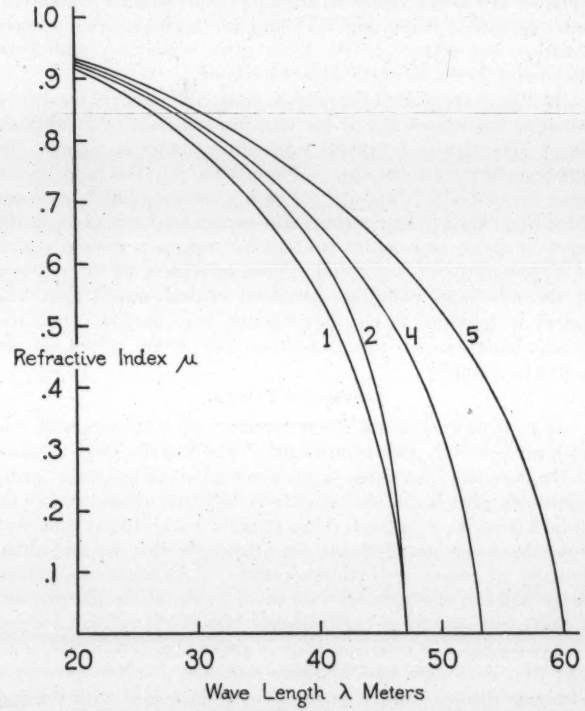
REFLECTION THEORY.

It is assumed that the lower levels of the atmosphere of the earth are relatively free from electrons and that the lower surface of the Kennelly-Heaviside layer, the region of relatively great electron density, is sharply marked. A radio ray transmitted in an upward direction would travel in a straight line and after reflection from the layer would return in a straight line to the earth. Actually, of course, the optical constants of the lower atmosphere merge without discontinuity into those of the electronic regions, so that a ray instead of being sharply reflected is refracted along a curved path. As often happens in theoretical physics, we consider first the simple case of sharp reflection and then pass to a refraction theory which is probably more in accord with the real state of things. Moreover, many of the conclusions of the refraction theory are found to be unchanged for the refraction theory.

We take the lower boundary of the layer, represented by AE in Fig. 4, to be a spherical surface parallel to the surface of the earth and at a height h above the earth. The radius of the earth is R. Let CAF be the path of a radio ray transmitted from C which is reflected from A at an angle ϕ and let the length of the

arc CF be $2s$; s subtends the angle θ at the centre of the earth. It is now assumed that when $2s$ is the observed skip distance for a specified wave-length, ϕ is the critical, or Snell, angle of total

FIG. 3.



Refractive indices of the Kennelly-Heaviside layer as a function of wave-length for rays in and perpendicular to the direction of the earth's magnetic field.

reflection of the wave from the layer. Since the refractive index of the atmosphere below the layer is unity, this assumption of course involves the condition that the refractive index of the layer is less than unity for those wave-lengths for which a skip distance exists. Otherwise a critical angle of total internal

reflection would be impossible and no skip zone would exist. If μ is the refractive index of the Kennelly-Heaviside layer, then from Snell's law,

$$\mu = \sin \phi . \tag{6}$$

From the geometry of Fig. 4,

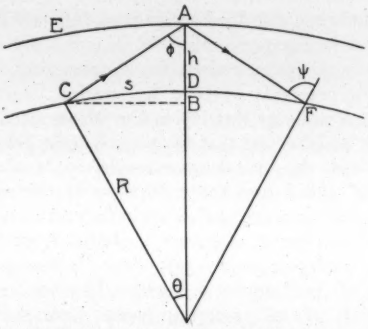
$$\sin \phi = CB/AC = R \sin \theta . / \{R^2 \sin^2 \theta + (R + h - R \cos \theta)^2\}^{\frac{1}{2}} , \tag{7}$$

and

$$s = R\theta . \tag{8}$$

The discussion is limited for the moment to the special case

FIG. 4.



Reflection from the Kennelly-Heaviside layer.

of dispersion represented by equation (1). When this equation was combined with (6), (7) and (8) to eliminate ϕ and θ, there resulted a relation between the unknown quantities h and C, the known constants R and λ_0, and the observed quantities λ and s. The substitution of the observed skip distances $2s$ for wave-lengths 16 and 40 metres into this relation yielded two equations in h and C. Eliminating C from these led to a quartic equation in h, which determined h and thence C. With these values of h and C, with $R = 3970$ miles and with $\lambda_0 = 214$ metres the $2s,\lambda$ curve was plotted and readjusted to approximate a least square solution. The final $2s,\lambda$ curve is shown in Fig. 1, and the values of h and C corresponding to this curve were 152 miles and 3.54×10^{-8}, respectively. With this value of C in (3), together with the usual values of the electronic mass and charge, N came out to be 3.95×10^5. The agreement between the theoretical

curve and the observed values in Fig. 1 is regarded as a confirmation of the correctness of the theory. Further, the values of h and N which have emerged appear reasonable. h is well within the aurora domain which, according to Störmer,[18] is between 50 and 300 miles above the earth. In this region, where the pressure may be of the order of 10^{-5} atmospheres, a simple calculation indicated that an electronic density of the order of 10^5 per c.c. is easily possible, the electrons supposedly being caused mainly by the ultra-violet light of the sun. The values for N and h appeared to be quite definitely established, as far as the present theory and calculations were concerned, for a variation in them of as little as 20 per cent. gave rise to discrepancies between the calculated and observed skip distances. Further, N and h did not depend at all critically on the value chosen for λ_0, changing, for example, by only a few per cent. when λ_0 was varied from 120 to 300 metres. The reason for this lay in the nature of the dispersion equation (1), and the fact that the wave-lengths below 60 metres were remote from the critical wave-length λ_0. It would therefore appear that N and h and the refraction of the rays are little influenced by time or space variations in the earth's magnetic field.

The dispersion curve, μ against λ, plotted from equation (1) with $\lambda_0 = 214$ metres and $N = 3.95 \times 10^4$, is shown by curve 1 (Fig. 3). The Snell angles ϕ calculated by means of (6) for wave-lengths 16, 21, 26, 32 and 40 metres were 71.8, 65.2, 58.4, 49.2 and 33.4 degrees, respectively. The angles which the direction of the down-coming wave at the edge of the skip zone makes with the vertical are for the respective wave-lengths 79.5, 70.6, 62.1, 51.8 and 34.8 degrees. These were calculated from the relation $\psi = \phi + \theta$ (Fig. 4).

Since h is roughly proportional to s, the fact that the night skip distances are about three times the day values indicates that h at night is three times the day value. The angles ψ will be greater at night than in the day by amounts corresponding to the change in θ.

Because of the bulge of the earth and the curvature of the layer, the curve of Fig. 1 ceased to exist at wave-length 14 metres. The Snell angles for wave-lengths shorter than this being so nearly 90° that even rays transmitted horizontally from the surface of the earth could not be totally reflected from the layer. Since it

[18] STÖRMER, *Proc. Phys. Soc. London*, 37, Part 2, 50D (1925).

appears that the overhead reflected (or refracted) wave and not the ground wave is all-important in long-distance short-wave radio transmission, the present theory indicates that communication over long distances by means of wave-lengths less than about 14 metres will be relatively difficult. This is due to the mechanism of the propagation entirely apart from the inherent technical difficulties in the apparatus for producing these very short waves with appreciable intensity. The few experiments which have been made in this region support this conclusion; for example, no long distances have been reached in the case of tests with 5-metre waves. It is hardly necessary to remark that due to unusual ultra-atmospheric conditions, etc., long-distance communication with very short waves may be successful at times. Such cases should prove to be the exception rather than the rule.

The foregoing calculations have been based on dispersion equation (1) which refers to one of the circularly polarized waves arising from propagation along the magnetic field. They are, furthermore, valid and accurate, within limits, for the general case of propagation of a wave with electric vector at a random and changing angle to the magnetic field, because the general case differs but slightly from the special case in the region of wave-lengths below 40 metres. This is evident when the μ, λ curves for the various dispersion equations, equations (1), (2), (4) and (5), are compared. These are plotted in Fig. 3, curves 1, 2, 4, and 5, respectively, using the constants $\lambda_0 = 214$ metres and $N = 3.95 \times 10^5$ or $C = 3.54 \times 10^{-8}$. For wave-lengths below 40 metres the refractive indices for the various curves are closely the same, and hence the Snell angles and the skip distances are approximately the same. In this connection curve 2 may be disregarded, for it refers to one of the component waves of propagation parallel to the magnetic field and wherever this exists the other component represented by curve 1 also must exist. The skip distances from curve 1 are all less than those from curve 2 and are therefore the ones which would be observed. The cases of propagation which differ most widely are, then, those represented by curves 1 and 4. These yield skip distances which differ by about sixty miles, those from curve 4 being the greater. If equation (4) instead of (1) had been used, h and N would have come out roughly 10 per cent. different from the values for (1). Therefore the values of h and N, which have been determined from curve 1, may be con-

sidered to be sufficiently accurate for the general case, which lies somewhere between the conditions of the curves 1 and 4; especially so, since the values can only be looked upon as rough averages of quantities which probably vary each moment of the day throughout the year. It follows at once from the approximate sameness of curves 4 and 5, which refer roughly to east and west propagation, and of curve 1, which refers to north and south propagation, that the skip distances do not vary appreciably with the compass direction of propagation. This is in accord with the experimental observations.

In the band of wave-lengths between 50 and 60 metres the curves of Fig. 3 suggest an appreciable variation in skip distance with the mode of propagation. For example, if the conditions of curve 2 obtained, we might expect a skip distance of 120 miles for a 50-metre wave, whereas under the conditions of curve 1 no skip distance would exist. There is some evidence that this effect exists, although the observations are none too certain because of the ground wave which may fill in the skip region. However, there is noticed at times an unusual flickering in the intensity of signals in this region which farther away are stronger and steadier.

Up to this point we have mentioned only the contribution of the electrons to the dispersion in the upper atmosphere, and we may now show that the more massive ions have little influence. In the dispersion formulas (1), (2), (4) and (5) the effect of the ions on μ may be calculated to a first approximation by adding another term (or terms, there being a term for each type of ion) similar to the last term of each equation, using the mass of the ion instead of the electron, which for, say, a nitrogen ion is 10^4 greater. The quantity $C = Ne^2/\pi m$ in the numerator of the ionic term is then 10^{-4} of the corresponding quantity for the electronic term for the same density of ions and electrons, the denominators being approximately the same for short waves. Therefore the ionic term will be negligibly small compared with the electronic term, except for very long waves outside of the usual radio range, unless there are at least 10^8 as many ions as electrons. Such a preponderance of ions is hardly to be expected in general. In view of this and of the good agreement of the theory with the observations, as indicated in Fig. 1, the conclusion may be emphasized that the reflection (or refraction) of radio waves in the layer is

caused in general by the electrons and not by the more massive ions. This may be regarded as a definite proof of the presence of considerable numbers of electrons in the upper atmosphere of the earth.

REFRACTION THEORY.

The physical conditions in the upper atmosphere are scarcely such as to render tenable a theory of reflection, for the transition from the low electron density of the lower atmosphere to the higher concentration of electrons in the Kennelly-Heaviside layer must be gradual and not abrupt. We therefore pass to a theory of refraction as offering a more exact picture of actual conditions, with the preliminary remark that the results of the refraction theory are for the most part identical with those of the reflection theory. This is to be expected since reflection is only a special case of refraction. We must now call attention to a circumstance which throws further doubt on a reflection theory and which supports a refraction theory. If we suppose, as has been done, that the edge of the skip zone marks the Snell angle of total reflection then, as we pass into the skip zone to points where reflection occurs at angles less than the critical angle, the reflected intensity will become less, but will not drop to zero, and in the case of rather oblique incidence, as with the 16-metre wave, the reflected intensity may be decreased by only a few per cent. It would therefore follow that the intensity of the signals would drop off very slowly as the skip zone was entered, never reaching low values except at nearly normal incidence, and even there not zero. It is well known, on the contrary, that the signal intensity at, say, a distance of one-fourth of the way in from the outer edge of the skip zone, is less than 10^{-4} of the intensity in the region beyond the skip zone. This discrepancy in the case of the reflection theory does not occur for the refraction theory.

The calculations become much simpler if we consider the case of a flat earth instead of the curved earth discussed heretofore. For a flat earth equation (7) of the reflection theory becomes

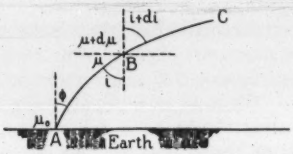
$$s = h \tan \phi \qquad (9)$$

which is of course a close approximation to (7) for short distances, up to 1000 miles. It will be shown later, however, that entirely apart from this approximation, the flat earth calculation can be referred to a curved earth with exactness.

The elaboration of a refraction theory requires the determination of the ray-paths of the wave, and these may not be determined explicitly without a knowledge of the variation of the optical constants of the atmosphere with the distance above the earth. The method of procedure has thereupon consisted of assuming a number of types of this variation and investigating the results of these assumptions.

It is assumed that the surface of the earth is flat and that the refractive index μ of the region lying above the earth is a

FIG. 5.



Refraction of a radio ray in an electron atmosphere of variable density.

function of y and not of x, where Y and X are the coördinate axes in the vertical and horizontal directions, respectively. μ is assumed finite, single-valued and continuous for a specified wave throughout the region. Let ABC (Fig. 5) be the ray which is projected from a point A on the surface of the earth at an angle ϕ with the vertical. Let μ_0 be the refractive index of the atmosphere at A. Let adjacent elements on either side of a point B on the curve make angles i and $i + di$ with the vertical, and let the refractive indices at these elements be μ and $\mu + d\mu$, respectively. Then from Snell's law

$$(\mu + d\mu)/\mu = (\sin i)/\sin (i + di).$$

Whence

$$\mu = \alpha \sin i,$$

where α is a constant of integration. From the initial conditions $\mu = \mu_0$, $i = \phi$, we obtain

$$\alpha = \mu_0 \sin \phi \tag{10}$$

and

$$\mu = (\mu_0 \sin \phi)/\sin i. \tag{11}$$

This is Snell's law generalized for the present problem. Since (11) must be satisfied at every point of the ray-path, the differential equation of the path is

$$dy/dx = -\cot i = -\sqrt{(\mu^2 - \alpha^2)/\alpha^2}, \tag{12}$$

where $\mu = f(y)$ and α is independent of x and y. This may not be integrated explicitly and therefore the equation of the ray-path can not be determined, unless $\mu = f(y)$ is known. In order to proceed farther various assumptions as to $f(y)$ are made and investigated in the following paragraphs.

Case 1. Electron Density Proportional to Height.—It is assumed that the electron density sets in at the surface of the earth and increases proportionally with the height above the earth. We write

$$N = \beta y \tag{13}$$

where N is the electron density at a point y above the surface of the earth. Then from (13) for each of the dispersion formulas (1), (2), (4) and (5),

$$\mu^2 = 1 - \gamma y, \tag{14}$$

where γ is determined by identifying (14) with each dispersion formula in turn. At the surface of the earth $y = 0$ and from (14) $\mu = 1$. Therefore, from (10)

$$\alpha = \sin \phi. \tag{15}$$

Introducing (14) into (12) and integrating gives for the equation of the ray-path,

$$x^2 = \{4\alpha^2(1 - \alpha^2 - \gamma y)\}/\gamma^2. \tag{16}$$

This is a parabola. The constant of integration has been eliminated by a shift of the curve along the X axis. The maximum height above the earth reached by the ray is

$$h = (1 - \alpha^2)/\gamma. \tag{17}$$

The ray comes down to the earth again at a distance $2x_0$ from its starting-point, where

$$x_0 = 2\alpha\sqrt{1 - \alpha^2}/\gamma. \tag{18}$$

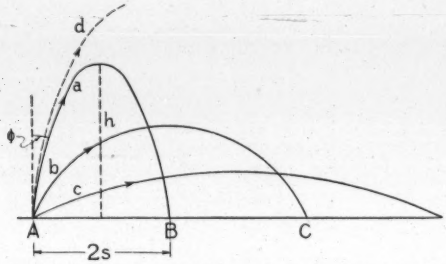
Combining (18) with (15) and (17) leads to

$$x_0 = 2h \tan \phi. \tag{19}$$

The ray-paths plotted from (16) for a specified wave transmitted from A (Fig. 6) at increasing angles ϕ are illustrated by curves a, b and c (Fig. 6). It is seen that as ϕ increases, h decreases and $2x_0$ increases. We may now identify AB, the distance between the feet of curve a, as the skip distance or the wave in question. This means that any other ray, such as d, whose angle of projection ϕ is less than that of ray α, will not return to the earth between points A and B; it may possibly return at some distant point or perhaps not at all. It follows,

therefore, that the law of electron distribution given by (13) ceases to hold above the summit of curve *a*. Just what will be the law above *h* is of course unknown, but this much can be said, that the electron density must increase less rapidly above *h* than it did below *h*. Therefore the "height of the Kennelly-Heaviside layer" means merely the distance above the earth to the region where the rate of increase in the electron density with the height becomes less. And because of its physical appeal, in

FIG. 6.



Refraction of radio rays transmitted from *A* at varying angles through an electronic atmosphere whose density is proportional to the height.

spite of other mathematical possibilities, we take this region to be the region of maximum electron density.

According to the supposition just made, that *AB* of curve *a* (Fig. 6) be the skip distance for the wave, formula (19) becomes

$$s = 2h \tan \phi . \qquad (20)$$

We might now introduce the observed skip distances into (20) and from the relation $\mu = \sin \phi$ at the height *h* and one of the dispersion equations determine *h* and *N*, just as was done in the case of reflection. It is not necessary to do this, however, because of the similarity of (20) and (9). It is seen that these formulas, which refer to a flat earth, are the same except that *h* of (20) is one-half *h* of (9). We may therefore conclude that if the skip-distance-refraction formula for a curved earth corresponding to (20) had been developed, it would be nearly the same as (7), which is the reflection formula for a curved earth corresponding to (9). This is true because only matters of geometry enter into the transformation from a curved to a flat earth. The final conclusion is that all the numerical facts of

this refraction case are exactly the same as those which have been derived from the reflection theory, except that h is one-half the h of the reflection theory. h is now 76 miles, but N, the calculated $2\ s,\lambda$ curve, the angles at which the rays at the edge of the skip zone descend to the earth, etc., are as before.

We may now emphasize the contention, previously stated, which pointed out that within the skip zone the intensity of the received signal is known to be 10^{-4} or less of the intensity in the surrounding signal zone. The refraction theory is in accord with this, for, referring to Fig. 6, there is no ray-path possible which connects the transmitter with a receiver inside the skip zone.

Case 1a.—The assumption of (13) and the result that for $y = 76$ miles $N = 3.95 \times 10^5$ electrons per c.c. is scarcely possible, for this would mean that at a height one mile above the earth there are 5×10^3 electrons per c.c. which is probably too large a number in general. If we then suppose that there are no electrons in the lower atmosphere up to a height h_0 and that the linear density law (13) sets in thereafter, it is easily seen that the ray-paths are straight lines in the region h_0, changing to arcs of paraboles in the region above h_0 and finally becoming straight lines again when the ray returns to levels below h_0. The skip-distance formula corresponding to (20) is in this case

$$s = (h_0 + 2h') \tan \phi . \qquad (21$$

$h' + h_0$ is the height of the summit of the ray above the earth, which is the height of the Heaviside layer. As h_0 increases from 0 to 76 miles, $h' + h_0$ increases from 76 to 152 miles, and we pass from the electron distribution of (13) to the case of abrupt reflection. Because of the similarity of (21) and (20) all that has been said of the applicability of the reflection theory results to Case 1 applies equally well to the present case of refraction.

Case 2. Electron Density Proportional to Square of Height.—In the notation of Case 1, it is assumed that

$$N = \beta y^2 . \qquad (22)$$

Proceeding exactly as in Case 1, the equation of the ray-path is

$$y = (\sqrt{1 - \alpha^2}/\sqrt{\gamma}) \sin (x\sqrt{\gamma}/\alpha) , \qquad (23)$$

which is a sine curve. The skip-distance formula is

$$s = (\pi h/2) \tan \phi \qquad (24)$$

and the height h comes out to be 97 miles.

Case 3. Electron Density Proportional to Exp. (Height).—It is assumed that

$$N = \beta\varepsilon^{y}, \tag{25}$$

and, proceeding as before, the equation of the ray-path is

$$x = \frac{\alpha}{\sqrt{1-\alpha^2}} \log_{\varepsilon}\left\{\frac{2(1-\alpha^2) - \gamma\varepsilon^{y} + 2\sqrt{(1-\alpha^2)(1-\gamma\varepsilon^{y}-\alpha^2)}}{\gamma\varepsilon^{y}}\right\}. \tag{26}$$

The skip-distance formula is

$$s = (\tan\phi)\log_{\varepsilon}\left\{2\varepsilon^{h} - 1 + 2\sqrt{(\varepsilon^{h}-1)\varepsilon^{h}}\right\}, \tag{27}$$

from which h is 149 miles. This is a special case of an exponential distribution, but possesses all the essential features of a more general type, which would be described by $N = \beta\varepsilon^{by}$, where b is a constant.

Since the skip-distance formulas (24) and (27) are similar to (9), the reflection theory results also apply to these cases, the height of the Heaviside layer being different, of course. Furthermore, corollary cases similar to Case 1*a* when carried out for Cases 2 and 3 give results exactly similar to those of Case 1*a*. This is so evident that the details are omitted.

Case 4. Electron Density Proportional to Square Root of the Height.—From the assumption that

$$N = \beta y^{\frac{1}{2}}, \tag{28}$$

the equation of the ray-path is

$$x = (4\alpha/\gamma^2)\sqrt{1-\gamma y^{\frac{1}{2}}}\left\{1 + 2\alpha^2/3 + (1-\gamma y^{\frac{1}{2}})/3\right\}. \tag{29}$$

The skip-distance formula is

$$s = \left(\frac{8}{3}\right)h\tan\phi\cdot(3/\cos^2\phi - 1). \tag{30}$$

It was found impossible to choose constants for the dispersion formulas such that (30) be in accord with the observed skip distances. Similar discrepancies with observation resulted from the assumption that $N = \beta y^{\frac{1}{3}}$ and $N = \beta y^{\frac{1}{4}}$.

Case 4a.—In this instance we modify Case 4, just as was done in Case 1*a*, and assume that no electrons exist below a height h_0 and that the electron distribution of Case 4 begins there. The skip-distance formula becomes:

$$s = h_0\tan\phi + \left(\frac{8}{3}\right)h'\tan\phi\cdot(3/\cos^2\phi - 1). \tag{31}$$

It was found that this formula was at variance with the observed skip distances as long as the second term was important, which occurred when h_0 was small. As h_0 becomes larger the second term becomes of less effect, and we approach the sharp reflection case and better agreement with observation.

In taking up the refraction cases 1, 2, and 3 in turn, we have passed from an electron distribution linear with the height progressively to electron distributions for which the N,y curve becomes more and more convex to the Y axis, approaching the distribution for sharp reflection, and have arrived at heights of the Heaviside layer which become in turn nearer to 152 miles. All these have yielded the same $\lambda,2s$ curve in agreement with observation, *i.e.*, the curve of Fig. 1, and therefore all are equally possible as far as this agreement is concerned. On the other hand, it has been shown in Case 4 that an electron distribution for which the N,y curve is concave to the Y axis led to pronounced discrepancies with the observed skip distances. This is all in comforting agreement with reasonable expectation. On general physical grounds one would expect an electron distribution whose rate of increase became greater with the height, whereas it is difficult to imagine the stable existence of a distribution whose rate of increase became less with the height. The conclusion to be derived is that the electron density N, during full daylight and averaged over all the days of the year, of the atmosphere of the earth increases with the height y in such a way that the N,y curve is for the most part convex to the Y axis, and that N reaches a maximum value of the order 10^5 for a height which is between 70 and 150 miles.

Again, the increase of the skip distance at night which indicates an increase in h is to be expected. For, with the removal of the sun's radiation (electromagnetic, electronic, etc.), which is probably the most potent cause of ionization in the atmosphere, recombination of the ions and electrons will occur. The electron density therefore becomes less and the radio rays must search higher altitudes before being turned back to the earth.

Certain details of the dispersion equations (1), (2), (4) and (5) are of interest. From all the equations at any wave-length less than $\lambda_0 = 214$ metres, μ decreases to zero and becomes imaginary as N (or C) increases. This means that a ray of this wave-length directed normally upwards passes through regions of

decreasing μ (and moves with increasing phase velocity) until it reaches that electron concentration for which $\mu = 0$ and there is totally reflected (or refracted) back to the earth. Therefore wave-lengths from about 60 to 200 metres will be totally reflected from the layer at all angles of incidence. The different component modes of polarization will penetrate to different heights. For waves shorter than 50 metres, N can not become large enough to make μ imaginary, since the calculations fix the maximum value of N as 10^5, and hence these rays are not totally reflected at normal incidence, but at a greater angle; this, of course, is the essence of the foregoing skip-distance theory.

For waves longer than 214 metres, μ decreases to zero and thence to imaginary values with increase of N in the cases of equations (2), (4) and (5). From equation (1), however, μ is always positive for these waves and increases from 1 as N grows larger. Therefore for waves longer than 214 metres the modes of polarization corresponding to equations (2), (4) and (5) will be totally reflected from the layer at all angles of incidence, the mode of equation (1), however, always being refracted upward and being probably lost. (Equation (4) has further mathematical complexities which appear to be of no physical significance.)

The prediction that these waves suffer total reflection, even at normal incidence, should perhaps admit of direct experimental proof.

For long waves greater than 500 metres, (2) reduces approximately to $\mu^2 = 1 - C\lambda\lambda_0$ and (4) and (5) to $\mu^2 = 1 - C\lambda^2$. These are about the same for small values of C, and the latter is the refraction formula for zero magnetic field. Hence the earth's magnetic field has little influence in the bending of the long waves, and therefore Larmor's development, which neglected the magnetic field of the earth and referred to long waves, is valid throughout.

FADING OF THE RECEIVED WAVE.

We must now call to mind certain well-known radio phenomena concerning the distortion of the received wave usually resulting in fading, *i.e.*, fluctuations in intensity, of continuous wave signals and in poor modulation and fading of speech signals. Two general types of fading are differentiated, which we now

recognize as attributable to quite different causes. One type, which is common to all wave-lengths, is an intensity fluctuation of relatively long period, of the order of a second or more. This is usually more noticeable at nearer distances than at greater distances from transmitter, and in general the longer the wave the slower the fluctuation. The other type is a fading at high speed, the signal intensity often varying from full strength to practically zero at a low audio-frequency of the order of, say, 100 oscillations per second. This appears as a change in the quality of the heterodyne note when continuous wave signals are being received and as bad distortion in the case of speech signals. The audio-frequency fading characteristic applies only to certain bands of wave-lengths at certain distances from the transmitter; it is, generally speaking, less observable in the day-time and at longer distances. More specifically, for waves longer than 800 metres, roughly, the high-speed fading rarely occurs; in the broadcast band, 300 to 600 metres, it is noticeable only at intermediate distances, at night especially, from about 100 to 1000 miles from the transmitter. In the region of shorter wave-lengths from 60 to 120 metres the high-speed fading is violent at night for distances from roughly 5 to 300 miles from the transmitter. For the wave-lengths 16 to 40 metres the audio-frequency fading is found in the flicker zones at the edge of the skip regions. Every detail of these fading phenomena finds a ready explanation in terms of the refraction ideas of this paper and, although qualitative, furnishes strong confirmation of those ideas.

With regard to the fading at low frequency, of a few seconds in period, we adopt the view, already suggested by many others, that this is due to a distortion of the received wave-front by motions of large clouds of the refracting electron medium. On the assumption, which appears very reasonable, that the bodily motions of the electron clouds are of the same order of velocity and extent as the air movements and currents in the lower atmosphere, one would expect low-frequency fluctuations in a wave refracted through such a medium. The phenomenon is a repetition on a larger and slower scale of the twinkling of the stars or of the unsteadiness of a scene viewed over the surface of a hot road. For longer waves motions of larger electron clouds are necessary to modify the wave-front, and these on the average would be expected to be slower than in the case of smaller clouds,

so that the fading would be slower. Further, for long distances for all wave-lengths the integrated cloud movements and hence the refraction effects would be expected to average out. This is all in accord with observation.

The audio-frequency fading is attributed to shifting interference patterns, and finds its optical analogue in the "light beats" of Airy and Righi.[19] Thus, considering the band of waves from 300 to 600 metres, which exhibit occasionally audio-frequency fading at distances from 100 to 1000 miles from the transmitter, it has been shown that the various polarization components of the wave, except that of equation (1), are totally reflected from the layer at all angles of incidence. Therefore, in this instance, any receiver, no matter where situated, may expect to receive in general four possible rays, the ground wave and the three overhead waves of equations (2), (4) and (5), which travel to the receiver by different paths. In the first 100 miles from the transmitter the ground wave is sufficiently intense to drown out any variations contributed by the overhead components. Beyond 100 miles the intensity of the ground wave for these wave-lengths becomes comparable with or less than that of the overhead waves, with the result that a complicated interference pattern of various states of polarization and intensities is formed about the receiver. Movements of the electron layer will cause this pattern to shift to and fro, thereby causing the rapid fluctuation of signal intensity. In daylight the electrons gather into low-flying clouds of relatively great density gradient, so that the paths of different overhead rays are relatively close together and the interference pattern becomes broad and hazy. Its movements therefore cause little change in the signals. At night, however, the electrons are more diffuse and their density gradient is much less, so that the ray-paths are more widely separated. The interference bands are therefore narrower and sharper and the motion of the pattern will cause rapid and violent intensity variations. At distances greater than 1500 miles the ray-paths are so long that the interference pattern becomes indistinct in both day and night and the average effects on it of electron cloud movements become less. It is interesting that these considerations call for the propagation of even these relatively long waves to great distances by an overhead route.

By similar reasoning fast fluctuations would not be expected

[19] AIRY and RIGHI, *Jour. de Phys.*, **2**, 437 (1883).

to occur for the very long waves at any place, because in the near distances the ground wave is strong and in the far distances the interference pattern is diffuse. In the case of the 16- to 40-metre band, it is easily seen that the possibilities for sharp interference exist only on the edge of the skip zones.

The discussion of the wave band from 60 to 120 metres is much the same. Here, however, the rapid fading occurs at distances as small as 5 miles from the transmitter. This means that for these waves at this distance the overhead components reach the receiver with an intensity comparable with that of the ground wave, even after travelling 100 miles or so up into the upper atmosphere and being reflected back at nearly normal incidence! There seems to be no escape from the conclusion that the ground wave in this case dies out rapidly and that the overhead components are very perfectly reflected. Thus what has long been an exceedingly puzzling phenomenon finds an equally startling explanation, startling at least until one accepts these ideas.

The various components of the wave, besides interfering, also may arrive at a receiver at different times, because of the different paths which they traverse. This will have no effect on the interference patterns just discussed, if the wave-trains are long, as in continuous wave signals, but will become an additional cause of distortion in the case of short wave-trains, such as the modulated waves of speech signals. In order to estimate the magnitude of this, we assume that the electron distribution of Case 1*a* is the one which actually exists for daylight conditions and take $h_0 = 30$ miles; $N = 0$ at this height. From the skip-distance data and equation (21), $h' = 61$ miles and $h_0 + h' = 91$ miles where $N = 3.95 \times 10^5$. This gives the electron-density gradient. From this and the dispersion equations (1), (2), (4) and (5), it is found that $\mu = 0$ at heights 69, 86, 78 and 64 miles, respectively. These are the heights where total reflection occurs for the respective waves. Assuming normal incidence, the difference of the paths of the rays from the transmitter to the region of total reflection and back to the receiver are roughly 20 miles, or 10^{-4} seconds. The rays, moreover, pursue their respective paths with different speeds, which are slower in the longer paths. Calculation shows that this will increase the time differences of the paths by two or three times, making them, say, 3×10^{-4} seconds. This would perhaps be barely perceptible in speech signals. At night, however,

the ray-path differences would be increased roughly three times, and the time differences would be of the order of 10^{-3} seconds or more, which would cause strong distortion of the speech signals. This estimate of the time differences of the rays has depended on the electron distribution assumed for the calculation. This suggests that an experimental analysis of the distortion in signals of wave-lengths 60 to 120 metres received at short distances from the transmitter would perhaps lead to more definite information about the electron distribution.

LONG-DISTANCE TRANSMISSION.

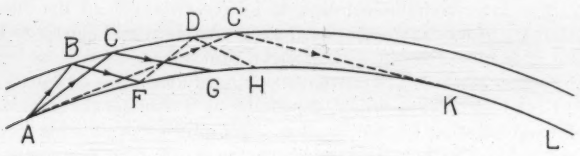
In the light of the foregoing conclusions it is of interest to consider the character of the reception at various distances from the transmitter. No attempt to cover all details will be entered upon, but a few cases deserve remark. It is convenient to make the diagrams from the reflection theory; the conclusions from these will be the same as from a refraction theory. In Fig. 7 the curved line AL is the surface of the earth and BC' the Kennelly-Heaviside layer at a height of 150 miles. Suppose that the radio-rays from the transmitter A are confined to the space BAC. The upper limiting ray AB descends to F where AF is the first skip region, is reflected back to D, down again to the earth at H, etc., continuing around by successive reflections. The lower limiting ray may be tangent to the earth as shown by AC' or may be inclined at an angle to the horizontal in the manner of AC. In the latter case if $AG < AH$, where $AH = 2AF$, there exists a second smaller skip region GH. From a continuation of the drawing, further skip zones are found at greater distances. These are possible, but perhaps not probable, because they become successively smaller and more ill-defined.

If the bundle of transmitted rays is limited on its lower side by the tangent ray AC', which is reflected to the earth again at K, the region KL can be reached by a ray from A only after at least one ground reflection and two layer reflections (refractions). With a layer height of 150 miles AK is 2000 miles. The region FK, on the other hand, can be reached by a ray which has experienced only one layer reflection and no ground reflection. Therefore, because the ground reflecting power may vary with the locality, one might expect possibilities of poorer signals in the region KL than in the region FK, quite apart from the difference

in remoteness; or, more graphically, the poor reception at station 5000 miles away may be due to a forest 2500 miles away. This distinction between the regions less and greater than 2000 miles would seem to be generally valid at all wave-lengths for which the direct ground wave is inoperative.

The observational data relevant to these questions are none too certain, but a recent program of tests with the 25.6-metre transmitter from this station (NKF) has permitted a few conclusions. A portion of the program involved the reception of

FIG. 7.



Paths taken by radio rays in travelling around the earth.

the signals at every hour of a 24-hour day by some forty stations scattered to 7000 miles distance. In the first place, the first daylight skip zone for 25.6 metres was found to be between 500 and 600 miles, which is in excellent agreement with Fig. 1. Secondly, no secondary skip zone, as *GH* (Fig. 7), appeared; the region from 700 to 1200 miles in daylight being unmistakably one of good signals. This meant merely that the lower transmitted rays were probably near to tangency with the earth, as *AC'* (Fig. 7). In this connection it might be possible to elevate the ray *AC'* until the second skip zone was produced, by properly loading and exciting the transmitting antenna.[20] Thirdly, the signals in the region from 2000 to 3000 miles appeared more uncertain than in the region within the 2000-mile mark. The observations referred mainly to overland waves and it would be of interest to repeat them with oversea waves.

In general, for the shorter waves, observations by many receiving stations in the United States indicate better signal reception in the region extending from the first skip zone to 2000 miles than in the region between 2000 and 4000 miles where at least one earth reflection is involved. At greater distances, however, from 5000 to 10,000 miles the short-wave signals are very

[20] VAN DER POL, *Proc. Phys. Soc. London*, **29**, 269 (1916–1917).

reliable, much more so than in the 2000- to 4000-mile zone. This is to be expected because, with increase of distance, there are a greater number of possible ray-paths connecting the transmitter and receiver, so that a local disturbance, such as a poor earth reflection, etc., of any one ray will have small influence on the signal. One might expect the inverse distance law of signal intensity to hold approximately in this region for the short waves. At the antipodes of the earth there is a concentration of ray-paths and a corresponding increase in signal strength. This has been frequently observed.

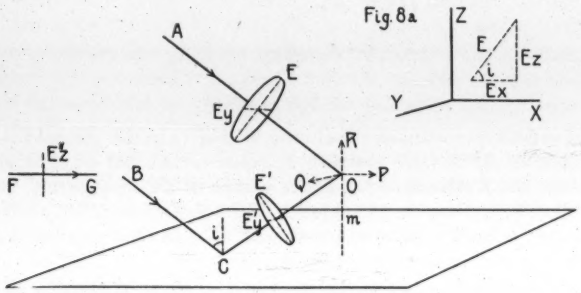
For radio communication over longer distances, of the interplanetary order, waves shorter than 40 metres would appear to be best able to pierce our own electron atmosphere as well as that of another planet. The circularly polarized long wave of equation (1) is of speculative utility, depending as it does on the intensity of magnetization of the electron atmosphere. Venturing even further into the realm of conjecture, the course of a ray proceeding in interplanetary space would be influenced by the electrons distributed from the sun. If this distribution were impartial in all directions, the electron density increases toward the sun, and the radio-ray would be diverted towards the sun. It might pass beyond the influence of the sun after a small deflection, or it might spiral towards the sun until it reached that electron density requisite for total reflection, whereupon it would pursue an enlarging spiral until free again.

POLARIZATION OF THE RECEIVED WAVE.

The state of polarization of the received wave may be derived from well-known principles of classical optics, and from this we are led to explanations of many phenomena of Hertz antenna reception and errors in loop-direction bearings. The discussion of course will be applicable to the general case of any polarized receiving system, of which the Hertz antenna and the loop are special types used in radio experiments. The analysis can be made quantitative only to a limited extent at the present time, for, first, the conditions with which we deal are variable and changing in both time and space, and second, many facts of the radio waves are unknown, notably their absorption in the upper atmosphere and their absorption in and reflection from the surface of the earth.

The electric field produced by the transmitted waves at a receiving antenna above the earth is regarded as due in general to the combination of three rays from the transmitter, a direct ray over the earth, a ray refracted downward from the Kennelly-Heaviside layer, and an upward ray which comes from the earth reflection of some descending ray. The possibility of a lateral ray, which bends around in the horizontal plane, is omitted from the discussion. The idea of the three rays at the receiver is not

FIG. 8.



A general case of three rays arriving at a receiver placed at O above the surface of the earth.

original with the author; it has long been entertained by radio experimenters and has appeared recently in papers by Appleton,[21] Smith-Rose,[22] and others.

Referring to Fig. 8, let O be a point at a height m above the surface of the earth. Denote the instantaneous values of the resultant electric field of the received wave at O by P, Q and R, which are measured along the rectangular axes X, Y and Z, respectively. X is taken in the true direction of the transmitter, Y perpendicular to X in the horizontal plane, and Z in the vertical direction. The electric field at O is assumed in general to be due to the superimposed effects of three rays from the transmitter, a direct ray, FG (Fig. 8), a down-coming ray AO, and an upward ray CO, which results from the reflection from the earth of a descending ray BC. The direct ray is taken to be always plane-polarized with its electric vector E''_z in the vertical plane. The

[21] *Proc. Roy. Soc.*, 109A, 621 (1925).
[22] *Nature*, 177, 90 (1925).

descending rays AO and BC, of exactly similar states of polarization, will in general not be plane-polarized and may be taken to be elliptically polarized, the ellipse being oriented in a random manner. The electric force of ray AO may therefore be resolved into a vector E_y along Y and a vector E in the vertical plane and normal to AO. In general E_y and E differ in phase and amplitude. E in turn is resolved into E_x and E_z, as shown in Fig. 8*a*. The polarization of the ray BCO is changed upon reflection, and after reflection may be represented by E'_y and E'; E' being resolved into E'_x and E'_z. We have then, for instantaneous values,

$$\left.\begin{aligned} P &= E_x + E'_x, \\ Q &= E_y + E'_y, \\ R &= E_z + E'_z + E''_z. \end{aligned}\right\} \tag{32}$$

Equations (32) denote the electric field at O in the general case. Since all the E's are periodic, of equal period, but of different phase and amplitude, P, Q and R will be of the same period, but will differ in phase and amplitude. Therefore the resultant electric field at O marks out an ellipsoid, with O at its centre, oriented at random with the coördinate axes.

The changes in phase and amplitude of the components of the electric vector of a wave introduced by the reflection of the wave from a plane surface are given by the well-known equations of Fresnel [23] of classical electromagnetic optics. Space will not be taken here to reproduce these equations. The results from the equations will, however, be appealed to a number of times in the following paragraphs.

RECEPTION WITH THE HERTZ ANTENNA.

Systematic observations on the character of the signals received with Hertz antennas have recently been initiated by Picard.[24] When considered in connection with the theoretical views just outlined, Picard's measurements appear to contribute exact quantitative evidence entirely in accord with the height of the Kennelly-Heaviside layer and the angles of the down-coming waves which have been calculated in earlier paragraphs.

The Hertz antenna is the ordinary Hertzian oscillator of the

[23] See, for example, ABRAHAM and FÖPPL, "Theorie der Electrizität," 1 (1907).

[24] *Proc. Inst. Rad. Eng.*, 14 (1926).

physicist, and in radio takes the form of two wires of equal length placed end to end in the same straight line, the inner ends being connected with suitable condensers and inductances for purposes of tuning and coupling to the amplifying apparatus. The Hertz antenna properly arranged, *i.e.*, with no disturbing reactions between the antenna, the amplifying apparatus, etc., and properly calibrated, may be used to measure the component of the electric field along the antenna due to the received wave.

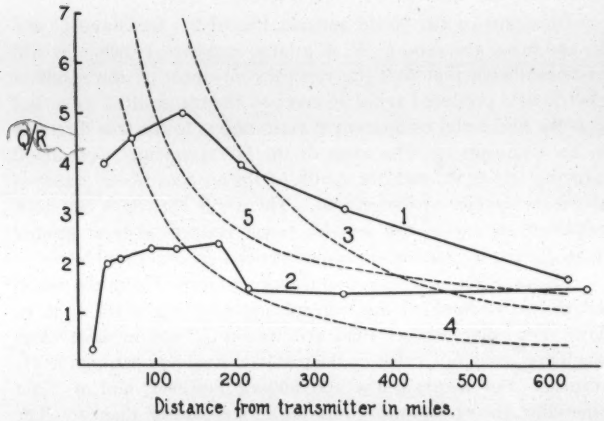
By means of the Hertz antenna Picard has measured Q and R, and hence the ratio Q/R, in a large number of cases. It will be remembered that R is the vertical component of the resultant electric field produced at the receiver by the transmitted wave and Q is the horizontal component at right angles to the true direction of the transmitter. The wires of the Hertz antenna were about 4 metres in length, with the centre of the antenna about 7 metres above the surface of the ground. The whole apparatus, antenna, amplifier, etc., was on a wooden tower erected on level ground in an open space remote from obstructions and overhead wires.

The Q/R ratios were found to vary in general with the wave-length, the distance of the transmitting station and the time of day. For waves longer than 200 metres R was in most cases much greater than Q, that is, the resultant field was predominently vertical. For waves below 100 metres, however, and at night especially, the Q/R ratios were as a rule greater than 1. The measurements of Q/R for 40- and 80-metre waves are plotted as ordinates in curves 1 and 2, respectively, of Fig. 9, against the distances of the sending station as abscissas. These measurements were taken in the evening between 5 and 9 P.M.; during these hours night-time radio conditions had already set in.

Knowledge of the optical constants of the earth is hardly sufficient to permit exact theoretical calculations of the Q/R curves. We may proceed, however, by assuming in turn that the earth is a perfect conductor and a perfectly transparent dielectric. *A priori*, the actual earth's surface may be expected to fall between these two ideal conditions, and if moist, or at sea, to approach more nearly the first condition than the second. This is borne out by the calculations. We must now assume that the down-coming ray AO (Fig. 8), when averaged over a finite interval of

time, is circulary polarized; this means that $E_y = E$. This assumption is the natural one to make, since the polarization is known to vary with the time (as evidenced by high-frequency fading) and since no reason can be advanced why any particular state of polarization should prevail. The assumption is supported by Picard's observation [24] that the Q/R ratios were entirely

FIG. 9.



The ratios Q/R of the horizontal to the vertical components of the electric field of the received waves as a function of the distance from the transmitter. Curves 1 and 2, observed for 40 and 80 metres, respectively. Curves 3, 4 and 5, calculated.

unaffected by various orientations of the plane of polarization of the wave actually emitted from the transmitter. Further, we shall assume for the moment that the sending station is so far away that the direct wave FG (Fig. 8) is non-existent.

Case 1. The Earth a Perfect Conductor.—The reflection from a perfect conductor is perfect. From Fresnel's equations the component of the electric field normal to the surface is not changed in phase upon reflection, and the component parallel to the surface suffers a phase change of π. Therefore from equations (32), referring to Figs. 8 and 8*a*,

$$Q = E_y - E'_y = E - E'.$$

Passing to root mean square values, assuming sine waves, and denoting the frequency by $\omega/2\pi$ and the time by t, we have

$$Q = \left\{\frac{1}{2\pi}\int_0^{2\pi} [E\sin\omega t - E\sin(\omega t+\delta)]^2\, d\omega t\right\}^{\frac{1}{2}},$$

$$= E\sqrt{1-\cos\delta}. \qquad (33)$$

δ is the phase difference at point O due to the difference in lengths of the ray-paths BCO and AO. In radians

$$\delta = 4\pi m\cos i\cdot/\lambda, \qquad (34)$$

where i is the angle of incidence of the descending rays.

In a similar manner

$$R = E_z + E'_z = (E+E')\sin i,$$

$$= \sin i\cdot\left\{\frac{1}{2\pi}\int_0^{2\pi} [E\sin\omega t + E\sin(\omega t+\delta)]^2\, d\omega t\right\}^{\frac{1}{2}},$$

$$= E\sin i\cdot\sqrt{1+\cos\delta}. \qquad (35)$$

Therefore

$$Q/R = \frac{1}{\sin i}\sqrt{\frac{1-\cos\delta}{1+\cos\delta}}. \qquad (36)$$

Taking the height of the Kennelly-Heaviside layer to be 250 miles, on the sharp reflection theory, and with $m = 7$ metres, the Q/R curves for wave-lengths 40 and 80 metres were calculated, and are plotted in curves 3 and 4 (Fig. 9), respectively.

Case 2. The Earth a Perfectly Transparent Dielectric.—In this case the reflection is not perfect. The refractive index μ of the earth is estimated to be 5 for all the radio wave-lengths under consideration, as judged from the known value 80 for the dielectric constant ε of pure water and from $\mu = \sqrt{\varepsilon}$. From equations (32), referring to Figs. 8 and 8*a*,

$$Q = E_y + E'_y = E + E'.$$

Introducing Fresnel's equations and passing to root mean square values, yields

$$Q = E\left\{\frac{1}{2\pi}\int_0^{2\pi} [\sin\omega t - a\sin(\omega t+\delta)]^2\, d\omega t\right\}^{\frac{1}{2}},$$

$$= E\sqrt{\frac{1}{2}(1+a^2-2a\cos\delta)}, \qquad (37)$$

where

$$a = \frac{\sin(i-r)}{\sin(i+r)},$$

i and r being the angles of incidence and refraction, respectively. i

and r are related by the Snell equation $\mu \sin i = \sin r$. A similar calculation for the vertical component gives

$$R = E_z + E'_z = (E + E') \sin i,$$

$$= E \sin i \cdot \left\{ \frac{1}{2\pi} \int_0^{2\pi} [\sin \omega t - b \sin (\omega t + \delta)]^2 \, d\omega t \right\}^{\frac{1}{2}},$$

$$= E \sin i \cdot \sqrt{\frac{1}{2}(1 + b^2 - 2b \cos \delta)}, \tag{38}$$

where

$$b = \frac{\tan (i - r)}{\tan (i + r)}.$$

Whence

$$Q/R = \frac{1}{\sin i} \sqrt{\frac{1 + a^2 - 2a \cos \delta}{1 + b^2 - 2b \cos \delta}}. \tag{39}$$

This relation is plotted in curve 5 (Fig. 9), which refers to either 40 or 80 metres. The difference between the curves for the two wave-lengths being inappreciable on the scale of Fig. 9. Changing μ from 5 to 10 produced no important changes in curve 5.

It is seen that the theoretical curves 3, 4 and 5 (Fig. 9), all rise to high values of Q/R for short distances from the transmitter, whereas the observed curves do not. The discrepancy is due to the neglect of the direct ray FG (Fig. 8). This ray contributes a vertical electric field, of increasing magnitude at the shorter distances, which on the average increases R and hence decreases the theoretical values of Q/R. With this variance at the short distances cleared away, the calculated curves on the basis of a perfectly conducting earth agree tolerably well with the observations, except perhaps at the greater distances above 500 miles. Here the theoretical curves are too low. Perhaps if the dielectric properties of the earth were taken into account at the same time this discrepancy would also disappear. Curve 5 for a transparent dielectric earth is apparently in disagreement with the observations, being approximately unchanged for the two wave-lengths. Actually the optical constants of the earth depend on both the dielectric and conductivity constants, and one may be more important than the other, depending on the locality, the wave-length, etc.[25] If these constants are known, Fresnel's equations will admit of exact calculations. The surface of the earth may, moreover, be complex,[26] for example, of dielectric

[25] VAN DER POL, "De Ingenieur," No. 38 (1925).

[26] SMITH-ROSE and BARFIELD, *Proc. Roy. Soc.*, **107**, 587 (1925).

properties on the surface and of good conductivity, due to moisture, a few feet down. A more detailed analysis than has been given would necessitate a complete experimental survey of the earth in the locality of the Hertz antenna.

In calculating the Q/R curves the height of the Kennelly-Heaviside layer was taken to be 250 miles, as this gave the best agreement with observations. A height of 150 miles gave unmistakable disagreement, the curves 3, 4 and 5 (Fig. 9) being shifted to shorter abscissas by about 60 or 70 miles. The 250-mile height for a summer night is in exact accord with the notions of earlier paragraphs. There the height was found to be 150 miles for daylight averaged over the year, which means roughly 100 miles in summer and 200 miles in winter, as judged from the seasonal variation in the skip distances. The night-time heights are two or three times the day values, which would give 200 to 300 miles for a summer night. We have been speaking from the standpoint of the sharp reflection theory. If we refer to the refraction theory of Case 1, all the heights just mentioned must be divided by two. It must be remarked that Picard's measurements, embodied in curves 1 and 2 (Fig. 9), supported by the present theory, offer a confirmation of the predicted angles of the rays descending from the Kennelly-Heaviside layer. Any other experiments for the determination of these angles would appear to be but variations of Picard's experiments and must be analyzed as these have been.

An experiment, none too simple, may be suggested by means of which i may be determined in an unambiguous manner, regardless of the nature of the ground. From equations (33) and (34) it follows that the values of Q pass through minimum and maximum values as m, the height of the antenna above the earth, is varied with all other conditions constant. The experiment consists of observing the two consecutive heights m_1 and m_2, for which Q is a minimum. Then i is given by the relation $\cos i = \lambda/4(m_2 - m_1)$. For, when Q is a minimum, $\cos \delta = 1$ from either (33) or (37), and hence δ is $k\pi$ at m_1, and $(k+1)\pi$ at m_2, k being an integer. Hence from (34) $4\pi m_2 \cos i./\lambda - 4\pi m_1 \cos i./\lambda = \pi$, or $\cos i = \lambda/4(m_2 - m_1)$. The experiment would be supposed to be possible even if the direct wave were present, for the direct wave, in theory at least, contributes nothing to Q. This experiment might be termed, depending upon the analogous

optical experiment in mind, either a measurement of the Lloyd's mirror system of interference fringes of the radio waves, or a Lippmann color photograph of the radio waves.

ERRORS IN RADIO-DIRECTION BEARINGS.

The errors in radio-direction bearings with loop antennas may be classed roughly as those due to the apparatus and those due to the character of the incoming waves. The first class, which arises from asymmetric reactions between the loop and the amplifying apparatus, from obstructions and wires in the vicinity of the loop, etc., is omitted from the present discussion. The second class arises from surface refraction and from refraction in the upper atmosphere. The surface refraction effect is also outside of the present discussion. It is due to a lateral wave, or to the interference between a lateral and a direct wave, the lateral wave being caused, for example, by oblique passage over the sea coast.[27] The type of error which we shall discuss is now recognized as being caused by rays refracted downward for the Kennelly-Heaviside layer. It is very erratic and may vary in magnitude from 0° to 180°, in short, completely around the compass; it is very widespread, being observed for all wave-lengths at certain distances from the transmitter; and as far as can be seen now is incurable by any simple remedy.

The factors entering into the theoretical consideration of this type of directional error are precisely those outlined in the case of the Hertz antenna. The resultant effect of three rays at the loop antenna must be calculated, the three rays being as before, the direct ray, a descending ray and a ray reflected upward from the ground. As is usual, the effect of these rays on the loop is calculated by means of the magnetic fields, although the electric fields would of course answer as well. Figs. 8 and 8*a* remain unchanged except that all the E's are replaced by H's, H denoting the magnetic field; in the case of the direct wave FG, the magnetic field is along Y and therefore is designated by H''_y. The resultant magnetic field P, Q, R at O is, for instantaneous values,

$$\left.\begin{aligned} P &= H_x + H'_x, \\ Q &= H_y + H'_y + H''_y, \\ R &= H_z + H'_z. \end{aligned}\right\} \qquad (40)$$

Since all the H's are periodic, of equal period, but of different

[27] ECKERSLEY, *Radio Rev.*, 1, 421 (1920).

phase and amplitude, P, Q and R will be of the same period but will differ in phase and amplitude. Therefore, just as in the case of the electric field, the resultant magnetic field at O marks out an ellipsoid, with O at its centre and oriented at random with the coördinate axes. The resultant ellipsoid will change with the height of the loop above the surface of the earth.

For a loop swinging around a vertical axis, as in the radio compass, we require the magnetic field in the XY plane. This is given by $P + Q$ or $(H_x + H'_x) + (H_y + H'_y + H''_y)$, which in the general case is an ellipse oriented at random to the X and Y axes. The orientation and eccentricity of the ellipse depend upon the relative phases and magnitudes of P and Q. In the general case of the elliptical field there will be a shallow minimum in signal intensity as the loop is rotated, the sharpness of the minimum increasing with the eccentricity of the ellipse. An observation of the position of the loop for the minimum, which may be shallow or sharp, will merely indicate the orientation of the ellipse, which obviously has no connection with the direction of the incoming rays. A sharp minimum of course is no indication that the direction given by the loop is the true direction of the transmitting station, it may or may not be. If P is equal to Q in magnitude and opposite in phase the ellipse becomes a circle, and there will be no change in signal intensity as the loop is rotated around a vertical axis. If P is zero the ellipse degenerates to a straight line along Y, and there is a sharp minimum position of the loop which gives the true direction of the incoming waves. This is the only case in which the directional bearing is correct. The converse is also true, namely, that if directional errors exist, P must have a value other than zero. Upon referring to Fig. 8, it is seen that this means that there must be a down-coming ray. The conclusions then are, that direction errors of necessity mean descending rays (under the assumption of no local errors and no lateral ray), and that descending rays will in general, although not necessarily, cause direction errors. Further, if the errors are great, say 45°, the intensity of the downward ray must be comparable with and perhaps greater than the intensity of the direct ray, and the angle of descent must be considerably inclined to the horizontal.

It follows at once that wherever the foregoing theory points to possibilities of rays descending at angles to the horizontal

greater than perhaps 20°, there will be erratic directional bearings, as long as the direct ray is sufficiently feeble. Thus, close to and very far from the transmitter the directional errors may be expected to be slight for all wave-lengths. For waves below 50 metres the variations will occur beyond the skip zones. For longer waves the errors will be prominent at the intermediate distances, from about 100 to 500 miles. This is all in accord with general observation, although the experimental data are far from complete. Indeed, an experimental survey of directional errors as a function of the time of day and year, of the wave-length, the distance of the transmitting station might yield information about the rapidity with which the direct wave dies out and the intensity of the overhead ray. Into the interpretation of such experiments the reflecting power of the ground around the receiving loop and the height of the loop above the ground will enter in an important manner.

Austin's [28] recent observations on the directional errors of long waves, 10,000 to 20,000 metres, are of interest in that they demonstrate that even for these long waves the descending ray at medium distances is comparable in intensity with the ground wave. This is true, however, only at night. For it was found that correct bearings were obtainable with these waves at all distances during the day, but that at night for distances from 100 to 300 miles from the transmitter the bearings fluctuated with errors of 30° or more. In those instances where the directional errors were pronounced, it was further observed that the tilt of the loop for the position of sharpest minimum changed both in altitude and asimuth as night-time conditions set in. This meant merely that the ellipsoidal magnetic field was changing at that time, as would be expected. Although the tilt of the loop for sharpest minimum of course determines the direction of the long axis of the ellipsoid and from this the relative values of the various magnetic components may be estimated in part, it would seem on the whole that little quantitative use could be made of the measurements of these tilts.

[28] *Proc. Int. Rad. Eng.*, 13, 3 and 409 (1925).

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

ON THE VISIBLE DECOMPOSITION OF SILVER HALIDE GRAINS BY LIGHT.[1]

By A. P. H. Trivelli and S. E. Sheppard.

MICROSCOPIC observations of the decomposition of individual crystal grains are described. Statistical observations on ordinary and desensitized grains are compared and a tentative theory of the photochemical decomposition is proposed. It is suggested that the photochemical decomposition is oriented in the crystal according to the gradients of ionic deformation, or perturbation of electron orbits following certain directions of growth. Since sensitivity nuclei, as also the reduced silver, will induce marked deformation in contiguous silver bromide, the decomposition becomes autocatalytically oriented. This explains the contrast in behavior between the special silver bromide crystals and emulsion grains, as well as the effect of size.

ON A SUPPOSED RELATION BETWEEN THE SENSITIZING OF SILVER HALIDE EMULSION AND THE BLEACHING-OUT OF DYES.[2]

By S. E. Sheppard.

THIS is a critical discussion of the suggestion of Knoche, Schmidt, Kögel and Steigmann that the sensitizing action of thiocarbamides is the same as their action on accelerating and bleaching-out of dyes. It is pointed out that in sensitizing photographic emulsions with thiocarbamides they are destroyed, with formation of silver sulphide before exposure, while in the case of dyes the thiocarbamides are present as such during exposure. Other contentions of Knoche and Schmidt are criticized.

* Communicated by the Director.

[1] Communication No. 235 from the Research Laboratories of the Eastman Kodak Company, and published in *J. Phys. Chem.*, **29**: 1568, 1925.

[2] Communication No. 263 from the Research Laboratories of the Eastman Kodak Company and published in *Phot. Ind.*, **24**: 301, 1926.

ON THE RELATION BETWEEN TIME AND INTENSITY IN PHOTOGRAPHIC EXPOSURE. III.[3]

By L. A. Jones, E. Huse, and V. C. Hall.

WORK has been continued on the failure of the photographic reciprocity law, $E = It$. The failure of this law using Panchromatic and Orthochromatic emulsions is somewhat greater than reported previously for high-speed non-color sensitive emulsions. Slow Ordinary and Lantern emulsions show very great failure and also a marked change of gamma with intensity. For fast plates, the variation of density with intensity is small, optimal intensity is at a low value, and gamma is independent of intensity. For slow plates, the density variation is great, optimal intensity high, and gamma drops at low intensities. As found by Kron, optimal intensity shifts to higher values with increasing development time.

Kron's usually accepted empirical law does not fit the observed data. An alternative form,

$$It = \frac{I_0 t_0}{2}\left[\left(\frac{I}{I_0}\right)^{a} + \left(\frac{I}{I_0}\right)^{-a}\right],$$

has been found to fit the observed data for fast plates over a range of 1 : 8,000,000 in intensity and to fit the data for slow plates at high intensities. The observed failure is greater than the calculated curve indicates for these emulsions at low intensities. This equation was suggested by Kron, but it did not fit his observations. The observed data thus far indicate that the dependence of gamma on intensity follows as a result of changes in the effective grain-size frequency function caused by a differential failure of the reciprocity law for grains of different sizes and sensitivities.

THE SPECTRAL DISTRIBUTION OF THE SENSITIVITY OF PHOTOGRAPHIC MATERIALS.[4]

By L. A. Jones and Otto Sandvik.

A NEW type of automatic monochromatic sensitometer is described, the unique feature of which is a sector wheel in which the apertures are spaced spirally about the centre of rotation.

[3] Communication No. 253 from the Research Laboratories of the Eastman Kodak Company and published in *J. Opt. Soc. Amer.*, **12**: 321, 1926.

[4] Communication No. 256 from the Research Laboratories of the Eastman Kodak Company and published in *J. Opt. Soc. Amer.*, **12**: 401, 1926.

While this sector wheel rotates at a uniform angular velocity, it is moved longitudinally so that the spirally arranged apertures travel in the proper relation to the photographic material. A cam plate attached to the shaft carrying the sector disc actuates an electromagnetic device which moves the photographic plate forward one step after exposure through the successive apertures. In this way twelve exposures increasing by consecutive powers of two are obtained.

A study of the spectral purity of a single monochromator showed that in certain parts of the spectrum the stray radiation present was about 50 per cent. of the total amount. To reduce this stray radiation to a minimum, two monochromatic illuminators were used in series.

The amount of spectral energy per square centimetre necessary to produce a silver deposit of unit density under definite development conditions was determined. The maximum sensitivity was found to be in the ultra-violet.

Gamma, the slope of the straight line portion of the characteristic curve, increased towards the red end of the spectrum.

The velocity of development, calculated by the Sheppard-Mees equation, has a maximum value in the ultra-violet.

CHARACTERISTICS AND ANOMALIES OF EMULSIONS ON DEVELOPMENT.[5]

By S. E. Sheppard.

ATTENTION is drawn to the variability of the behavior of photographic emulsions, particularly negative emulsions when developed for different times. Instances of anomalous characteristic curves given in the literature are confirmed by much new data. It is pointed out that anomalous kinds of emulsions have a lower degree of reproducibility, in the sense of giving an identical family of characteristic curves in different times of development. It is further pointed out that they are much less amenable to the applications of laws of tone reproduction, to automatic processing, and to the increased reliance upon photography in science and technology. From consideration of the data presented, a division of emulsions into orthophotic and anorthophotic is suggested; this

[5] Communication No. 261 from the Research Laboratories of the Eastman Kodak Company, and published in *Phot. J.*, **66**: 190, 1926.

division is based on the behavior for different times of development under standard conditions. Orthophotic emulsions given a family of characteristic or H. and D. curves, the straight line portion of which unambiguously defines a single tie-point. This tie-point may lie above, upon or below the axis of exposure and according to this a further sub-classification of orthophotic emulsions is defined. It is shown that all types of industrially used emulsions, including portrait emulsions, are producible conforming to the orthophotic type, but showing specific variations. The relation of these variations and anomalies to the distribution of sensitivity and latent image among the grains is discussed in the light of recent discoveries.

THE EFFECT OF SCRATCHES AND CUTS ON THE STRENGTH OF MOTION PICTURE FILM.*

By S. E. Sheppard and S. S. Sweet.

INVESTIGATIONS of the effect of scratches and cuts upon the strength of motion picture film has been extended to processed film in different conditions. Scratches were made on the film by drawing the film at a constant rate under a point bearing a given load. The effect of the scratch was determined both by measurement of the elastic curve and by folding tests. The investigation on the whole confirms previous conclusions as to the effect of scratches upon bare film support not coated with emulsion. There appears to be little effect of scratches upon the strength until comparatively deep scratches are produced. Contrary to statements which have been made upon this point, this indifference to scratches was found to be increased rather than lessened as the film becomes older and more hardened. Raw films having a large elongation show marked reduction of this elongation for even slight scratches which do not much affect the breaking load, but when this elongation is reduced, as by heat, even this effect becomes much less notable. Slight nicks in the side of the film have a similar effect upon the elongation to scratches, as observed by Briefer, but this effect again becomes smaller as the film becomes harder.

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*Communication No. 251 from the Research Laboratories of the Eastman Kodak Company and published in *Trans. Soc. Mot. Pic. Eng.*, No. 24, 1926.

NEOCYANINE: A NEW SENSITIZER FOR THE INFRA-RED.[1]

By M. L. Dundon, A. L. Schoen, and R. M. Briggs.

HITHERTO the most efficient sensitizers for the photography of the near infra-red have been dicyanine and kryptocyanine. In the preparation of kryptocyanine, Dr. H. T. Clarke, of this Laboratory, noticed that the condensation gave rise to a dye much more soluble than kryptocyanine and which therefore was not separated from the solution. This dye, named neocyanine, was tested as a sensitizer and found to have a broad sensitizing band extending from 700$\mu\mu$ to 900$\mu\mu$ with a maximum about 830$\mu\mu$.

Manufacture of Insulin.—The preparation of insulin on a commercial scale is described by HORACE A. SHONLE (*Jour. Chem. Ed.*, 1926, 3, 134–147). Insulin is a hormone or chemical messenger which is secreted by the islands of Langerhans in the pancreas, and is thrown into the blood stream. It governs the metabolism of carbohydrates; and a deficient secretion of insulin gives rise to the disease known as diabetes mellitus. Insulin was first prepared by F. G. Banting, C. H. Best, and J. J. R. Macleod, of the University of Toronto, in 1920.

In the commercial process, the pancreas is removed from freshly slaughtered hogs and cattle, is immediately placed in a refrigerator, and is transported to the factory in iced containers. The glands are finely ground in a meat chopper. The various processes of manufacture are conducted in enameled or earthenware apparatus. The ground pancreatic tissue is thoroughly mixed for several hours with an equal volume of ethyl alcohol containing 10 per cent. of pure methyl alcohol and 1 per cent. of sulphuric acid. The extract is then separated by centrifugation, using a rubber-lined basket. The solid residue is extracted with 60 per cent. alcohol, and the extract is separated by means of the centrifuge. The two extracts are combined, and freed from suspended solids by filtration through fluted filter paper or by passage through a supercentrifuge. The alcohol content of the resulting liquid is about 60 per cent. This liquid is partially neutralized, then concentrated in vacuum pans at a temperature not exceeding 25° C. to one-twelfth to one-fifteenth its original volume. The fat which separates is removed by skimming and filtration. Two methods exist for the further purification of the insulin.

In one method, the solution is half-saturated with ammonium sulphate. The flocculent precipitate, which separates, is collected and dissolved in warm acidified alcohol. The resulting solution is neutralized, and kept at a temperature of 5° C. for several days. A precipitate forms, is collected, dried *in vacuo*, and dissolved in

[1] Communication No. 255 from the Research Laboratories of the Eastman Kodak Company and published in *J. Opt. Soc. Amer.*, 12: 397, 1926.

acidified water. The hydrogen-ion concentration of the resulting solution is adjusted between pH 7.3 and 7.5. Inert proteins precipitate and are removed. Then the hydrogen-ion concentration of the clear solution is adjusted to pH 5.0, the iso-electric point of insulin. After standing at a temperature of 5° C. for several days, the precipitate is collected and dissolved in acidulated water. The reaction of this solution is made pH 5.0; and the insulin precipitates on standing at a temperature of 5° C. for several days.

In the other method, inert proteins are precipitated from the concentrated fat-free solution by addition of alcohol until that compound has reached a concentration of 80 per cent. The precipitate is removed by filtration. Alcohol is added to the filtrate until 93 per cent. of that compound is present. The precipitate, which now forms, contains the insulin. The precipitate is collected, and dissolved in acidulated water. The reaction of the resulting solution is adjusted to a hydrogen-ion concentration of pH 5.0 to precipitate the insulin. The procedure of solution and precipitation is repeated to increase the purity of the product. This method exists in several modifications.

The insulin, prepared by either method, is dissolved in acidified water, having a hydrogen-ion concentration of pH 2.5, and containing 0.1 per cent. of trikresol as a bactericide, and sufficient sodium chloride to render it isotonic with the blood. This solution of insulin is tested biologically, sterilized by passage through a Berkefeld filter, and placed in sterile ampules. In the testing of a single commercial lot of insulin as many as 1000 rabbits may be used. Determination is first made of the amount of insulin solution per kilogram of body-weight required to produce convulsions in rabbits on subcutaneous injection. Then the dose per kilogram of body-weight is determined, which lowers the dextrose (glucose) content of the blood of a fasting rabbit from its normal value of 0.1 per cent. to 0.045 per cent. for a period of five hours after injection. Lastly, the insulin is administered to diabetic patients to determine its ability to enable the diabetic to metabolize properly the carbohydrates of his diet. The "unit" of insulin is one-third the amount required to lower the dextrose content of the blood of a fasting rabbit of 2 kilograms body-weight to 0.045 per cent. for a period of five hours in from 60 to 70 per cent. of the group of test animals.

It is uncertain whether insulin is a protein or a compound associated with a protein fraction of the pancreas. Some of its reactions indicate it to be a primary proteose.

The convulsions which occur as the result of an overdose of insulin are antidoted instantly by either oral or hypodermic administration of sugar.

The preparation of insulin on a commercial scale has revolutionized the treatment of diabetes mellitus. The physician can now administer the deficient hormone hypodermically to the diabetic patient, and thereby restore his carbohydrate metabolism to its normal state. J. S. H.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

EVALUATION OF COMMERCIAL VANILLA OLEORESINS.[1]

By J. B. Wilson and J. W. Sale.

[ABSTRACT.]

IN AN investigation conducted in the Bureau of Chemistry authentic vanilla oleoresins for use as standards were prepared by extracting three varieties of beans with a suitable solvent and removing the solvent under reduced pressure. These authentic samples, together with commercial vanilla oleoresins, were prepared in different ways for analysis, and the resulting products were subjected to analysis. Based on the results thus obtained, the following determinations in analyzing commercial vanilla oleoresins are recommended:

(1) On the well-mixed oleoresin.
  (*a*) Ash.
  (*b*) Total alkalinity of ash.
(2) On an extract of the oleoresin in 95 per cent. alcohol.
  (*a*) Non-volatile solids (at 100° C.).
  (*b*) Vanillin.
  (*c*) Glycerol.
(3) On the water extract of the oleoresin after extraction with 95 per cent. alcohol.
  (*a*) Non-volatile solids (at 100° C.).
  (*b*) Caramel.
(4) On an extract of the oleoresin in 47.5 per cent. alcohol.
  (*a*) Vanilla resin.
  (*b*) Wichmann lead number.

Express the total alkalinity of ash as cubic centimetres of 1 N acid per 100 grams oleoresin. Express all other results in per cent. based on weight of oleoresin. Calculate ratio of ash to total alkalinity of ash, ratio of non-volatile solids on the extract 95 per cent. alcohol to non-volatile solids on the water extract, and ratio of vanilla resin in extract 47.5 per cent. alcohol to vanillin in extract 95 per cent. alcohol.

* Communicated by the Chief of the Bureau.

[1] Published in *Ind. Eng. Chem.*, **18** (March, 1926): 283–285.

POLLUTED ATMOSPHERE A FACTOR IN THE DETERIORATION OF BOOKBINDING LEATHER.[2]

By F. P. Veitch, R. W. Frey, and L. R. Leinbach.

[ABSTRACT.]

EXPERIMENTS recently conducted in the Bureau of Chemistry show that polluted atmosphere is an important factor in the deterioration of bookbinding leather. The products of fuel combustion, which pollute the atmosphere in most of our cities, are very corrosive. They attack the leather of bindings exposed to them and hasten its deterioration.

The effect of these atmospheric impurities may be counteracted by the application of finishes or dressings, either during the process of manufacturing the leather or when the book is bound.

THE ISO-ELECTRIC POINTS OF PROTEINS.[3]

By F. A. Csonka, J. C. Murphy, and D. B. Jones.

[ABSTRACT.]

THE iso-electric points of a large number of proteins have been determined by shaking buffers having a pH range from 4.0 to 6.8 with an excess of the protein investigated, and precipitating the dissolved protein in the clear filtrate with tungstic acid. The Sörensen value of the buffer filtrate in which was produced the least turbidity is taken as the iso-electric point of the protein.

The results obtained show that those proteins having the greater solubility in aqueous solutions have the lower iso-electric points, and that a correlation exists between the iso-electric points of proteins of the same group. The iso-electric points of albumins were found to range in general from pH 4 to pH 5, those of globulins from pH 5 to pH 5.5, and those of prolamins from pH 6 to pH 6.5.

Proteins requiring the greater quantity of ammonium sulphate for their precipitation from saline solutions have lower iso-electric points than proteins which require less ammonium sulphate for their precipitation. Thus the β-globulins have lower iso-electric points than the α-globulins.

Albumins were found to be more soluble, in the buffers used, on the alkaline side of their iso-electric points, while globulins, on the other hand, showed greater solubility on the acid side.

[2] Published in *J. Am. Leather Chem. Assoc.*, **21** (March, 1926) : 156.

[3] Published in *J. Am. Chem. Soc.*, **48** (March, 1926) : 768.

ELECTRODE VESSEL FOR LIQUIDS HEAVIER AND LIGHTER THAN THE LIQUID JUNCTION POTENTIAL ELIMINATOR.[4]

By L. E. Dawson.

[ABSTRACT.]

AN ELECTRODE vessel for the measurement of the hydrogen-ion concentration of solutions having a density equal to or greater or less than that of the bridge solution has been developed in the Bureau of Chemistry. Sharp and reproducible liquid junctions or flowing junctions can also be conveniently and rapidly made between the electrode solution and the bridge solution by including the feature embodied in the apparatus of F. A. Elliott and Elliott and Acree. The ground-glass joints and the intricate stop-cocks of the Elliott-Acree apparatus, which can be made and repaired only by well-equipped and highly skilled glass-blowers, are not used, thus making the new apparatus less expensive and more durable. Furthermore, solutions containing suspended matter, such as quinhydrone in quinhydrone electrode work or soil suspensions which would settle down into the bridge liquid in the Elliott or Elliott-Acree apparatus, may be tested without developing this difficulty.

THE PREPARATION AND PROPERTIES OF METHYL-ISOPROPYL-QUINOLINE YELLOW.[5]

By Max Phillips and Marshall J. Goss.

[ABSTRACT.]

2.8-Diamethyl-5-*iso*propyl-quinoline was prepared from 2-amino-*p*-cymene by the application of the Doebner and Miller synthesis. Condensed with phthalic anhydride, it gave methyl-*iso*propyl-quinoline yellow.

A comparison of the absorption of methyl-*iso*propyl-quinoline yellow with that of quinoline yellow failed to reveal any appreciable displacement in the absorption maximum through the methyl-*iso*propyl substitution.

The disulpho derivative of methyl-*iso*propyl-quinoline yellow dyes wool and silk a greenish yellow. It is equal in fastness to the corresponding quinoline yellow derivative (Quinoline Yellow S).

[4] Published in *J. Am. Chem. Soc.*, **47** (Aug., 1925) : 2172–2173.

[5] Published in *J. Am. Chem. Soc.*, **48** (March, 1926) : 823.

The absorption of the disulpho derivative as compared with that of Quinoline Yellow S failed to indicate any appreciable difference in the absorption maximum through the methyl-*iso*propyl substitution.

IDENTIFICATION OF PHENOLS BY MEANS OF THE SPECTROSCOPE. II.*

By H. Wales and S. Palkin.

[ABSTRACT.]

A LARGE number of phenolic compounds have been identified by the method based on coupling them with *p*-nitrobenzene diazonium chloride, extracting the dye with a suitable solvent, and measuring the absorption spectra of the potassium salt in three different solvents.

Azo dye derivatives of forty-five phenolic compounds were examined spectrophotometrically. Absorption spectra maxima for solutions of these dyes in water, alcohol, and acetone were recorded.

The John Ericsson Medal.—The American Society of Swedish Engineers has recently established a medal to be known as the John Ericsson Medal, which will be awarded every second year to an American of Swedish birth or descent or a Swedish citizen in recognition of distinguished accomplishments in science and engineering. The medal will be of solid gold and will be inscribed: "The American Society of Swedish Engineers—The John Ericsson Medal." On the reverse will be the emblem of the Society and the inscription: "To ————, Year ————, for distinguished achievements in science and engineering." The first award of this medal will be made in Washington in May next, during the time of the unveiling of the John Ericsson Monument.

Metallic Uranium.—J. F. GOGGIN, J. J. CRONIN, H. C. FOGO, and C. JAMES, of the University of New Hampshire (*Ind. and Eng. Chem.*, 1926, **18**, 114–116), have prepared metallic uranium of a high degree of purity by fusion of a mixture of anhydrous uranium chloride and sublimed metallic calcium. The fusion was made in an alundum crucible which was placed in a tightly closed steel cylinder, subjected to a high vacuum, and electrically heated. After complete cooling, the slag of calcium chloride was removed by a current of cold water. One ingot of metallic uranium, produced by this process, weighed 1500 grams, and contained less than 0.01 per cent. of iron. The same process has been used by these investigators for the preparation of zirconium, beryllium, and thorium. J. S. H.

* Published in *J. Am. Chem. Soc.*, **48** (March, 1926): 810.

NOTES FROM THE U. S. BUREAU OF MINES.*

RECORD OF THE PITTSBURGH TESTING STATION STANDARD DYNAMITE.

By S. P. Howell.

DATA have been assembled regarding the various lots of standard 40 per cent. straight nitroglycerin dynamite purchased and used at the Pittsburgh Experiment Station of the Bureau of Mines, from the beginning of its work of testing for permissibility up to the present. Thirteen samples of 40 per cent. straight nitroglycerin dynamite, individual samples of which were manufactured at average intervals of seventeen months, were compared with each other as to their percentage defective strength by comparing each sample with the previous sample and the subsequent sample. A record is thus procured of the strength continuity of these thirteen consecutive samples, together with certain of their chemical and physical characteristics. The average loss in strength of each sample was but 1 per cent. in seventeen months.

Explosives have been tested in the United States to determine their permissibility for use in coal mines during a period of over seventeen years. Among the tests made on such explosives, that utilizing the Bureau of Mines' ballistic pendulum for determining the U.D.C. (unit deflective charge) has been in constant use. In the beginning it was expedient to choose as a standard of "strength" the then commonly known 40 per cent. straight nitroglycerin dynamite and to express the U.D.C. in terms of the number of grams of the explosive under examination, which produces a swing of the pendulum equivalent to the swing produced by 227 grams (8 ounces) of the standard 40 per cent. dynamite.

Further details of the tests are shown in Information 6004, of the Bureau of Mines, which was recently published.

THIRTEENTH SEMI-ANNUAL MOTOR GASOLINE SURVEY.

By E. C. Lane, H. M. Thorne, and John Devine.

DURING the past six years the Bureau of Mines has made semi-annual surveys of the gasoline marketed in the United States, the survey just completed being the thirteenth in the series. The

* Communicated by the Director.

cities in which samples have been collected have been chosen as representative of the more important marketing territories as it is obviously impracticable to obtain a sample of every gasoline sold in the entire country.

Although motor gasoline marketed in the United States in January of this year was, on the average, slightly more volatile than that sold in January, 1925, the improvement in quality is too small to be of importance. In other words, there is no evidence that any radical change in the quality of gasoline is being made at the present time. The tendency has continued toward uniformity in gasoline, which has been noted in the past several years. There is apparently a distinct difference between "winter" and "summer" gasoline, the gasoline marketed during the winter being more volatile than that sold during the summer. Detailed tables are presented in Serial 2740, recently issued by the bureau.

SAFEGUARDING WORKMEN AT OIL DERRICKS.

By H. C. Miller.

THE bureau has completed a study of methods of safeguarding workmen at oil derricks. Safety devices in the oil fields are in a constant state of development, and each year many improvements are effected and changes made for the greater protection of the workers. It was found that progress has been especially rapid along improvements in methods of constructing derricks and safeguarding the men who work in them. The results of the bureau's study, with recommendations on the best practices to follow, will be issued as the second of a series of technical papers on oil-field safety. The first of the series, on mechanical guards in rotary drilling, has been published.

AMMONIA GAS MASK.

By A. C. Fieldner.

TESTS were completed and approval issued of the G. M. D. ammonia gas mask. The mask will protect the wearer in any concentration of ammonia gases that could be borne without excessive irritation of the skin. The mask has a face-piece with non-breakable eye-glasses, which forms a pocket over the face and permits breathing through the nose, from a canister filled with

a specially impregnated, activated charcoal. This is the second mask to be approved by the bureau for use in ammonia gases. It is manufactured by the Mine Safety Appliances Company. Details are given in a report being issued as a serial of the bureau.

DETERMINATION OF METALLIC LEAD IN LEAD MIXTURES.

Metallurgists of the Intermountain experiment station developed a method for the determination of metallic lead in mixtures of other lead compounds. The method consists of dissolving and filtering out all lead compounds which would be attacked by silver nitrate, by means of a solution of sodium hydroxide. This solution does not affect any metallic lead present. The metallic lead is then removed from the residue by treatment with silver nitrate. The method gives accurate results, and presence of other substances, such as iron and zinc compounds, and carbon, does not affect the results. The method was needed in studies being conducted on the pyrometallurgy of lead.

MEASUREMENTS OF TEMPERATURES IN OPEN-HEARTH FURNACE.

In the course of an investigation of refractories service conditions in the open-hearth steel furnace, metallurgists of the bureau have measured temperatures in several open-hearth furnaces in the Pittsburgh district. Fundamental data were obtained on the condition necessary for accurate measurements of temperature, a subject which has become of increasing interest in control of steel-making and prevention of overheating of the refractories used in the roof and walls. It was found that near the end of the heat, at the high temperatures employed, the temperature is practically uniform throughout the melting chamber. Temperature measurements through the brick walls showed that in general thick insulated walls have only slightly higher inside temperature than thin air-cooled and water-cooled walls, but the thick walls fuse more quickly than thin walls, on account of the slower exchange of heat.

The Acoustics of Auditoriums.—The increasing density of population in cities and the demand for entertainment has caused the construction of many theatres and lecture halls of large size and

brought out new problems of heating, lighting, ventilation and auditory quality. These have been to a large extent solved, at least if the builders and owners of halls are willing to take advantage of the data now available. Electric lighting, under the development of the work of the illuminating engineer, has been brought to a high degree of efficiency. Heating and ventilation have been also extensively studied and it is now possible to construct a hall of large capacity in which comfortable conditions may be maintained without difficulty. The auditory quality, however, is often overlooked. In a large part of modern entertainments this is, indeed, not so important, for the "silent drama" is now much in vogue, but still music, lectures and the old-fashioned plays are common and for them satisfactory auditory qualities are needed.

Acoustic efficiency has received less attention, at least from the strictly scientific point of view. Halls are generally left entirely to architects, who have standards of artistic effect that do not meet practical requirements. The same is true of college buildings and laboratories. The question of the best method of constructing a large auditorium has been made the subject of an essay by Paul R. Heyl, Senior Physicist in the Sound Laboratory of the Bureau of Standards. The essay appears in Circular 300 of the Bureau.

Elaborate scientific investigation of the conditions under which speech can be satisfactorily heard in halls seems to date from an investigation by Prof. W. C. Sabine, who in 1895 studied the subject in connection with difficulties that existed in the auditorium of the Fogg Art Museum at Harvard University, this hall having been found practically unusable. The principal difficulties in halls are: Echo, reverberation, dead spots and sound foci. Echo is the definite repetition of the sound at an appreciable interval after utterance, and, as every one knows, is annoying to both speaker and hearers. Reverberation is an indefinite repetition of the sound and is stated in the essay to be in moderate development advantageous. Dead spots are simply points at which the sound is seriously diminished and sound foci are points at which it is materially increased, often somewhat annoyingly.

In planning an auditorium three factors must be considered: Shape, size and interior finish. The general design should avoid curved walls or domed ceilings. Introduction of features for artistic effect is almost certain to be detrimental to the acoustics of the room. (It is to be hoped that architects will give close attention to this point.) Auditoriums of rectangular shape have been the most satisfactory. Size is, of course, much dependent on the purpose for which the room is to be mainly used. A theatre is usually to be smaller than one intended for orchestral or choral performances. A liberal use of coffering (construction of deeply sunk panels) in the ceiling and sloping upper walls are advantages. H. L.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting, Wednesday, April 21, 1926.)

The stated monthly meeting was called to order at eight-fifteen P.M. by President Wm. C. L. Eglin.

The President announced that the minutes of the last meeting had been published in full in the April number of the JOURNAL, and that unless there were objection they would be approved as printed. No objection was offered and the minutes were thereupon declared approved.

The Secretary made a report from the Board of Managers, upon the recommendation of the Board, and moved that the following two gentlemen be elected to Honorary Membership in the Institute:

Prof. Niels Bohr—Professor of Physics in Copenhagen University, for his brilliant research work which has led to the development of the theory of the structure of the atom which has come to be known as "Bohr's theory."

Dr. Samuel Rea—Former President of the Pennsylvania Railroad, for his brilliant labors in planning and constructing railroads, and in the design and construction of the great modern terminals, tunnels and bridges.

The motion was seconded and was unanimously adopted, and Professor Bohr and Doctor Rea were declared to be elected as Honorary Members.

The Secretary announced, with sincere regret, the deaths of three members of the Institute—Messrs. Randal Morgan, Clement B. Newbold, and M. S. Kemmerer—since the last meeting of the Institute.

The Secretary gave notice of the change of date for the next stated meeting. It will be held on May twelfth instead of May nineteenth. This day has been constituted The Medal Day of the Institute, on which all of the Medals which have been awarded during the year will be presented. Nine such medals are to be presented on Wednesday, May twelfth. The exercises will be held at three-thirty in the afternoon. The members are all urged to attend.

The Secretary also announced that on Friday, May twenty-first, at four in the afternoon, a specially painted portrait of Dr. Samuel Insull, of Chicago, will be formally presented to the Institute by the donors of it. Doctor Insull is one of the leading Public Utilities men of the United States, and is the founder of the Franklin Medal of the Institute. The presentation will be accompanied by appropriate exercises, to which the members of the Institute are invited.

The Secretary also announced that seven new members had been elected to the Institute since the last stated meeting.

The President expressed the regret of the Board of Managers at the deaths of the three members, especially that of Mr. Randal Morgan, a long-time friend and supporter of the Institute. He stated that the Board had appointed a Committee to prepare a special minute concerning the death of Mr. Morgan.

As there was no further business, the President introduced as the lecturer of the evening, Dr. L. W. McKeehan, of the Bell Telephone Laboratories, Inc., who spoke in a very interesting fashion of the results of his researches upon magnetostriction.

The lecture was followed by a brief discussion, after which the meeting was adjourned by vote of thanks to Doctor McKeehan for his excellent paper.

The meeting adjourned at nine-twelve.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, April 7, 1926.)

HALL OF THE COMMITTEE,
PHILADELPHIA, April 7, 1926.

MR. CLARENCE A. HALL, *Chairman.*

The following reports were presented for final action:

No. 2843: Akeley Moving Picture Camera.

This camera is provided with an aluminum box, making it light and rigid, and is adapted for the taking of both still and moving pictures.

Some of its advantages are: The quickness with which it can be fixed upon the tripod, adjusted and clamped in position; the ease with which the tripod can be set up, its stability, and the readiness with which its head can be brought to a horizontal position; the ease with which the film box can be removed and replaced; the form of this box which enables any part of the film to be used without spoilage of the rest; the type of finder that makes it possible to follow the movement of an object in any plane and show it in its natural upright position; the matched twin lenses that bring to the eye and to the film identical pictures, and the mounting of the lenses on a sliding base by means of which one set of lenses can be quickly changed for another set of different focal length. The cranking handle is fixed to the case and can be folded out of the way when not in use. It is a one-man camera since its position can be controlled readily by one hand and the handle for making exposures can be operated by the other.

This report, recommending the award of the John Price Wetherill Medal to Mr. Carl Akeley, of New York City, "in consideration of the combination of new and ingenious devices embodied in the Akeley Camera and its satisfactory operation in the field for which it was designed," was adopted.

No. 2851: Astronomical Work of Dr. George E. Hale.

This report, recommending the award of the Elliott Cresson Medal to Dr. George Ellery Hale, of Washington, D. C., "in consideration of his outstanding researches and fundamental discoveries relating to the sun and the solar atmosphere," was adopted.

The following report was presented for first reading:

No. 2815: Making Acetaldehyde from Acetylene.

Dr. William C. L. Eglin, President of the Institute, reported that the officers of the United Gas Improvement Company had expressed a desire to establish a fund for a medal to be known as the Walton Clark Medal, this

medal to be awarded for invention, improvement or discovery in the gas industry or in the manufacture of gas. After discussion, Doctor McClenahan, Secretary of the Institute, was asked to report to the Board of Managers that it is the opinion of the Committee on Science and the Arts that the acceptance of a fund for the establishment of the Walton Clark Medal is desirable.

GEORGE A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, April 14, 1926.)

RESIDENT.

DR. HENRY ARNSTEIN, Consulting Engineer, 418 East Roosevelt Boulevard, Philadelphia, Penna.

MR. RAYMOND B. COOKSON, Electrical and Mechanical Engineer, 136 South Sixteenth Street. For Mail: 5243 Warrington Avenue, Philadelphia, Penna.

DR. LOUIS F. FIESER, Chemist, Bryn Mawr College, Bryn Mawr, Penna.

MR. CHARLES S. LEOPOLD, Consulting Engineer, 213 South Broad Street, Philadelphia, Penna.

MR. MATHEW F. MAURY, Banker, 807 Packard Building, Philadelphia, Penna.

MR. JOHN A. ROULTON, Resident Engineer, Rainey-Wood Coke Company, Swedeland, Penna. For Mail: Norris Apartments, Norristown, Penna.

NON-RESIDENT.

MR. PAUL S. BAUER, Student, Cruft Laboratory, Harvard University, Cambridge, Mass.

MR. J. H. MANNING, Vice-president, Stone and Webster, Inc., 147 Milk Street, Boston, Mass.

TRANSFERS.

CONTRIBUTING MEMBERSHIP.

MR. BRUCE WYLE, Reading Company, Reading Terminal, Philadelphia, Penna.

RESIDENT TO NON-RESIDENT.

MR. F. J. CHESTERMAN, 416 Seventh Avenue, Pittsburgh, Penna.

CHANGES OF ADDRESS.

MR. JOHN IRWIN BRIGHT, Ardmore, Penna.

MR. GEORGE E. CABOT, 169 Marlborough Street, Boston, Mass.

LIEUT. JAMES W. COTTRELL, 409 Bellevue Avenue, Hammonton, N. J.

MR. JAMES G. DETWILER, The Texas Company, Whitehall Building, 17 Battery Place, New York City, N. Y.

MR. HAROLD GOODWIN, JR., 1817 Lindley Avenue, Philadelphia, Penna.

MR. WILLIAM B. HALSEY, 9120 Ninety-seventh Street, Woodhaven, N. Y.

MR. N. G. HERRESHOFF, 6 Wally Street, Bristol, R. I.

MR. MAX M. LEVY, 600 West 115th Street, New York City, N. Y.

MR. CHARLES E. SARGENT, Box 371, Lakeland, Fla.

MR. ROYAL B. STEVENS, Lehigh Telephone Company, Markle Bank Building, Hazleton, Penna.
MR. LOWNDES TAYLOR, 2006 Shunk Street, Philadelphia, Penna.
MR. EARL H. WELTZ, 701 Packard Building, Fifteenth and Chestnut Streets, Philadelphia, Penna.
MR. R. A. WIDDICOMBE, 1120 Lake Shore Drive, 3B, Chicago, Ill.
MR. ALFRED L. WILLIAMS, 1814 Spruce Street, Philadelphia, Penna.

NECROLOGY.

Mr. M. S. Kemmerer, Mauch Chunk, Penna.
Mr. Randal Morgan, Philadelphia, Penna.
Mr. Clement B. Newbold, Philadelphia, Penna.

LIBRARY NOTES.

RECENT ADDITIONS.

Archimedes. Über schwimmende Körper. Die Sandzahl. Ostwald's Klassiker der exakten Wissenschaften No. 213. 1925.
British Association for the Advancement of Science.—Report of the Ninety-third Meeting, 1925. 1926.
Chemical Society of London.—Annual Reports on the Progress of Chemistry, 1925. Vol. 22. 1926.
FARADAY, MICHAEL.—Experimentelle Untersuchungen über das Verhalten von Gold (und anderen Metallen) zum Licht. Ostwald's Klassiker der exakten Wissenschaften No. 214. 1925.
FOWLE, FREDERICK E.—Smithsonian Physical Tables. Seventh edition. 1923.
KÄHLER, K.—Elektrizität der Gewitter. 1924.
KAYSER, H.—Tabelle der Schwingungszahlen. 1925.
KEARTON, W. J.—Turbo-blowers and Compressors. 1926.
Klimschs Jahrbuch. Vol. 19. 1926.
PEARSON, HERBERT P.—Waterproofing Textile Fabrics. 1924.
QUEMPER DE LANASCOL, A.—Géometrie du Compas. 1925.
Royal Society of London.—Philosophical Transactions. Series A. Vol. 225. 1926.
SIM, JAMES.—Steam Condensing Plant. 1925.
Société Française de Photographie.—XX^e Salon International de Photographie, 1925. 1926.
STEWART, ALFRED W.—Recent Advances in Physical and Inorganic Chemistry. Fifth edition. 1926.
THORPE, SIR EDWARD.—A Dictionary of Applied Chemistry. Revised and enlarged edition. Vol. 6. 1926.
TURNER, T. HENRY, and BUDGEN, N. F.—Metal Spraying. 1926.
WIEN, W., and HARMS, F., Editors.—Handbuch der Experimentalphysik. Vol. 2, Mechanik der Massenpunkte und der starren Körper, by P. A. Haas. 1926.

BOOK REVIEWS.

RECENT ADVANCES IN PHYSICAL AND INORGANIC CHEMISTRY. By Alfred W. Stewart, D.Sc., University of Glasgow. Fifth edition, xi–312 pages, 8vo, plates and illustrations in text. New York, Longmans, Green and Company, 1926. Price, $6.50.

This is an excellent summary of the data that have accumulated in the inorganic field of physical chemistry in recent years. A dozen new chapters have been written, giving in clear and concise form the facts concerning hafnium, mass-spectroscopy, segregation of isotopes, atomic structure, active hydrogen, new hydrides, intense drying and the Tesla luminescence spectra. The author states that only three chapters have been left in the form in which they were in the previous edition. A large part of the volume has been devoted, as might be expected, to the researches that have increased the knowledge of the structure of the atom. The author leans decidedly to the static theory of atomic structure which is treated at considerable length. The final chapter gives a most interesting and valuable historical review of the atomic theory from its origin in the dawn of scientific speculation among the Greeks to the elaborate experiments and theories of to-day. A paragraph, covering the years from 1914 to 1918, gives a painful reminder of the war, stating that British scientists were, during those years, so occupied in other channels than pure research that little was accomplished in the latter field, but that in the "undisturbed atmosphere of the United States" such work was possible, and during this period G. N. Lewis put forward his cubical atom theory with its concomitant view that the valency bond could best be represented by a pair of electrons held in common by two united atomic systems. Even this work was but little noticed in the stress of war.

All through the book are to be found these instructive historical notes, together with descriptions of the methods now used in studying the nature of the atom and the phenomena of atomic action. A striking chapter is that on the effect of thorough drying on the properties of substances. Many years ago Wanklyn showed that perfectly dry chlorine does not act on perfectly dry fused sodium. Later, Dixon showed that a perfectly dry mixture of carbon monoxide and oxygen cannot be exploded by an electric spark, but a trace of moisture will activate the mass. Recent researches have gone much further and this book describes many of these, showing the drastic influences of thorough drying on melting and boiling-points. Baker found that the vapor density of ether and methanol were very much higher when they were perfectly dry than when in the ordinary condition.

The book is eminently adapted to enable the more mature chemist to "catch up" with the modern knowledge of physical chemistry and atomic theories in the inorganic field. HENRY LEFFMANN.

XXe SALON INTERNATIONAL DE PHOTOGRAPHIE, 1925. Société Française de Photographie, Paris. 15 pages, 48 plates, 9½ × 12½ inches, stiff paper.

The present issue of this annual is somewhat more elaborate in point of mechanical execution than that of the preceding year in that the plates are printed on one side of the paper. There is also a marked difference in the color of the paper, which is white or nearly so, instead of the buff tint of

last year's production, which is especially pleasing for art studies. Nevertheless the tableaux, which include still-life, figures in motion and portraits, are of the usual high standard of excellence of the productions of this Society. Gray, blacks and sepia tones are employed with good effect in keeping with the nature of the subject.

Apart from their artistic merit, the plates constitute examples of superior press-work scarcely distinguishable from photo-prints.

LUCIEN E. PICOLET.

IL VOLO TRANSPOLARE. By Col. Ing. Umberto Nobile, Director of the establishment for aeronautic construction in Rome. Pamphlet, 27 pages, illustrations and maps, 8vo. Rome, 1925.

This is a dissertation upon the plan for a transpolar journey starting from Rome. A concise account is given of the earlier voyages to the North Pole, from which it appears that in the fifteenth century, the brothers Zeno and Pietro Querini began such journeys, the main object being to obtain a route to India. Another Italian explorer took up the work in the latter part of the sixteenth century, but lost his life in the attempt. Henry Hudson's voyage in 1607 was the next in importance. Later voyages are noted, but there seems to be no reference to Elisha Kent Kane's expedition in 1853.

Numerous photogravures give details of the dirigible which is to be used for the journey, and several excellent maps show the routes pursued by the more recent polar travellers, including Peary's famous journey.

HENRY LEFFMANN.

PRESSION DE LA LUMIÈRE. Par Pierre Lebedef. Traduit du Russe par T. Kousmine, Chef de Travaux de Physique à l'Université de Lausanne. 71 pages, 9 × 6 inches, paper. Paris, Librairie Scientifique Albert Blanchard, 1926. Price, 7f.50.

Of the many persons who have a little more than a casual interest in striking phenomena of physical science, there are perhaps few who have not noticed the little apparatus devised by Crookes many years ago to demonstrate the pressure of light that is to be found in the shop-window of nearly every dealer in optical goods. Most of the text-books of physics describe it, but in general do not dwell upon the subject at more than brief length. Crookes' demonstration was in the main qualitative. Though numerous other investigators earlier and later than Crookes occupied themselves with the subject, to Maxwell is generally accorded the credit of demonstrating the relation between radiant energy absorbed, the velocity of light and the pressure exerted upon the absorbing surface.

The present pamphlet is a record of the investigations of the late Professor Lebedef on this important phenomenon of radiation. There are three main divisions of the work: First, on the repulsive force of radiating bodies; second, experimental research on the pressure of light; third, experimental researches on the pressure of light upon gases. A biographical sketch of the author is given at the end. The account of these experiments and their results is given in full detail with numerous references to the work of other investigators. The pamphlet is No. IX of a collection of monographs from foreign

sources published in French under the direction of Prof. G. Juvet, of the University of Neuchatel. By the numerous French-reading men of science in this country the availability of this important monograph will doubtless be deeply appreciated. LUCIEN E. PICOLET.

ELECTRICAL MEASURING INSTRUMENTS AND SUPPLY METERS. By D. J. Bolton, B.Sc., A.M.I.E.E., Lecturer in Electrical Engineering, The Polytechnic, Regent Street, W. xvi–328 pages, 8½ × 5½ inches, cloth, illustrated. The Directly Useful Technical Series. New York, E. P. Dutton and Company, 1923. Price, $5.

Not a few books have been written on this particular branch of electrical engineering. Some of them made their appearance long ago, that is long ago as relates to electrical matters and not of immediate applicability as a result of later developments, others, of relatively recent date and representative of existing practice. However fully a subject under development may be treated in existing works, if only to present the latest advances and to eliminate the description of supplanted apparatus whose proper place has passed to books of a historical character, a new book which includes the surviving of the old and the promising of the new is always a welcome arrival.

In keeping with the aim of the Directly Useful Series, the subject-matter of this work is presented from a highly practical point of view along with an accompaniment of summarized theoretical explanation. In a compact volume it embraces the broad field of current-measuring instruments and supply-meters with which are included magnetic-testing instruments and pyrometers. The apparatus described are grouped either according to kind of measurement or to the class of operating force employed. In the discussion of the more commonly used types—moving iron and coil—a section is devoted in each chapter to the design of windings in order to emphasize the relative advantages as to sensitivity, power-consumption and the like. A feature of the illustrations of apparatus, which are numerous and well-executed, is that wherever possible, the scale of dimensions is given on the figure. There are also numerous skeleton and circuit diagrams. The division and scope of the work are best exhibited by the chapter headings which follow: I. Component Parts and General Structure. II. Electrical Details—Resistances and Transformers. III. Hot Wire Ammeters and Voltmeters. IV. Electrostatic Voltmeters. V. Moving Iron Ammeters and Voltmeters. VI. Moving Coil (Permanent Magnet) Ammeters and Voltmeters. VII. Dynamometer Instruments. VIII. Induction Instruments. IX. Supply Meters—General. X. Supply Meters—Motor Type. XI. Supply Meters—Other Types and Fittings. XII. Direct Current Galvanometers. XIII. A. C. Galvanometers and Oscillographs. XIV. Null Tests and Standardization. XV. Commercial Resistance Measurements: Ohmmeters and Testing Sets. XVI. Frequency and Power Factor Meters; Synchroscopes. XVII. Iron Testing Instruments. XVIII. Pyrometers.

The apparatus described is naturally of English manufacture, but much of the technological detail is of a general character quite independent of characteristics of locality, and besides it is doubtful if in this age of active international intercommunication any satisfactory piece of electrical apparatus is not substantially duplicated here, with the possible exception of such ingenious but

unusual instruments as the mercury motor and the electrolytic meters. The book is an exceedingly satisfactory reference work for the engineer and a valuable work for the student who can find the time to specialize in the subject to the extent afforded by this attractive manual.

LUCIEN E. PICOLET.

DIE PHOTOGRAPHISCH-CHEMISCHE INDUSTRIE. By Friedrich Wentzel, Eng. D. xvii–363 pages, 43 illustrations, paper-bound, 8vo. Dresden and Leipzig, Theodor Steinkopff, 1926. Price, 18.50 marks.

The enormous development of photography is largely due to the invention of the dry plate and to the methods for increasing the sensitiveness of emulsions. The dry plate enables the taking of pictures remote from the dark-room and deferring the development until convenient times; the modern high-speed emulsion renders possible the taking of moving objects under a great variety of conditions. A French photographer once remarked that he had been told by a manufacturer of mustard that it was not the material that people put on their food, but that which they spilled on the plate that made the bulk of the sales and the photographer added that a large part of the business of modern photographic supply houses is dependent on the failures of amateurs rather than on the successful pictures. However that may be, a vast amount of interesting and valuable material has been given to the world in the last fifty years since the dry-plate and rapid emulsions have been made available at reasonable prices. The daguerreotype was certainly an artistic production in skilled hands. It is doubtful if for portraiture any other procedure equals it, but the length of exposure and the fact that no duplication except by additional sitting is possible, renders it merely of historic value.

The book under review is an excellent example of the thoroughness of German work. Not only is a wide field of photographic technology covered, but a very large amount of information is given concerning photographic procedures from exposure to final drying, all kinds of supports for the emulsion being considered. The great ingenuity that has been employed in designing and constructing machinery for large-scale production is well set forth.

The volume is one of a series entitled "Technische Fortschrittsberichte," being intended to describe in separate volumes the leading departments of chemical technology. Of course, in each department the immense mass of material renders strict selection and abstraction necessary. This work is very well done in the present volume. A perusal of the book will give an excellent idea of the present state of photographic manufacture. The literature of the field has been well searched and its essential information set down. A special note is given to a summary of the literature that has been consulted. It is certainly instructive to note that the periodical literature is limited to French, German and English, the last including, of course, both British and American journals. Only two American journals are noted, *Industrial and Engineering Chemistry* and the JOURNAL OF THE FRANKLIN INSTITUTE. It seems that the United States has not yet produced a photographic journal of the standing of the *B. J. P.* or the two well-known French publications. The publications of the Research Laboratory of the Eastman Kodak Company are noted and commended. To one who is interested in photography from the scientific point of view or for its many applications other than portraiture, landscape and still-life, it does

seem that most of our American journals are devoting too much attention to the artistic side. Pretty pictures seem to be the main effort. That among these the nude is very much in evidence may be simply one of the many expressions of what Agnes Repplier termed the "Repeal of Reticence," apparently a dominating impulse now-a-days.

Doctor Wentzel's book can be recommended to all interested in photography either as technologist or user of photographic material. The numerous illustrations add much to the clearness and usefulness of the text. An instructive account is given of the making of some of the familiar color plates. It is stated that an autochrome plate 13 × 18 centimetres contains about 140 million starch granules. The details of the manufacture of these plates and also of the Agfa plates, which have come lately into the market as direct rivals of the autochrome, are given in considerable detail. Recent information is given on the peculiar methods of combined development and fixing; also development after fixing. A good index and table of contents add to the serviceability of the book.

HENRY LEFFMANN.

ÉLÉMENTS D'ASTROPHYSIQUE, INTRODUCTION À L'ÉTUDE DE L'ÉNERGÉTIQUE SOLAIRE ET STELLAIRE. Par Albert Nodon, Docteur és Sciences, Ex-adjoint à l'Observatorie de Meudon, Président de la Société astronomique de Bordeaux. viii–244 pages, 8½ × 5½ inches, paper. Paris, Librairie Scientifique Albert Blanchard, 1926. Price, 20 francs.

To stellar energy may be traced the source of all movement, power and life of the entire universe. If its ultimate sources cannot be surmised, much less disclosed, its observable phenomena are of capital importance, and interest in its measurement has grown apace in recent years. Moreover studies in radiation, resulting in profound modification of atomic theory and energy concepts, have added zest to the prosecution of this subject by their better applicability to the observable facts than the theories formerly available; and radiation is the only means for astronomical observation.

The work is divided into two separate parts of which the first, which occupies three-quarters of the volume, is a comprehensive outline of the physics of the stars divested of all abstruse formulas. The second part contains a collection of quantitative physical data arranged in topical form. Before proceeding to an examination of stellar phenomena, the fundamentals of the physics of radiation are reviewed at considerable length, thus, the atom, the electron, the Bohr atom, quanta, ionization and wave-length, pressure of radiation are a few of the topics of this introductory matter. Following this ground-work the specific topics of the stellar universe are considered. Representative of these may be noted the opacity of stellar atmospheres, origin of stellar heat, classification of stars, nebulæ, stellar equilibrium, the sun, the corona, energy spectrum, discontinuity of the ether, gravitation, and extent of the universe.

The liberal bibliographical references and frequent reference by numbered topic to the formulated material of the second part of the book are of special value to the serious reader. Within the compass of the book itself, however, he will find not alone a lucid account of stellar phenomena and their logical analysis by the methods of modern physics, but an equally lucid *résumé* of the methods employed.

LUCIEN E. PICOLET.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 220, Comparison of Tests on Airplane Propellers in Flight with Wind-tunnel Model Tests on Similar Forms. By W. F. Durand and E. P. Lesley. 29 pages, illustrations, quarto. Washington, Government Printing Office, 1926. Price, fifteen cents.

The purpose of this investigation was to determine the performance, characteristics, and coefficients of full-sized air propellers in flight and to compare these results with those derived from wind-tunnel tests on reduced scale models of similar geometrical form.

The full-scale equipment comprised five propellers in combination with a VE-7 airplane and Wright E-4 engine. This part of the work was carried out at the Langley Memorial Aeronautical Laboratory, between May 1 and August 24, 1924, and was under the immediate charge of Mr. Lesley. The model or wind-tunnel part of the investigation was carried out at the aerodynamic laboratory of Stanford University and was under the immediate charge of Doctor Durand.

A comparison of the curves for full-scale results with those derived from the model tests shows that while the efficiencies realized in flight are close to those derived from model tests, both thrust developed and power absorbed in flight are from 6 to 10 per cent. greater than would be expected from the results of model tests.

Report No. 224, An Investigation of the Coefficient of Discharge of Liquids through Small Round Orifices. By W. F. Joachim. 10 pages, illustrations, quarto. Washington, Government Printing Office, 1926. Price, five cents.

The work covered by this report was undertaken in connection with a general investigation of fuel injection engine principles as applied to engines for aircraft propulsion, the specified purpose being to obtain information on the coefficient of discharge of small round orifices suitable for use as fuel injection nozzles.

Flow of the liquids tested under high pressure was obtained with an intensifier consisting of a 5-inch piston driving a direct connected ¾-inch hydraulic plunger. The large piston was operated by compressed air and the time required for the displacement of a definite volume by the hydraulic plunger was measured with an electrically operated stop-watch. The coefficients were determined as the ratio of the actual to the theoretical rate of flow where the theoretical flow was obtained by the usual simple formula for the discharge of liquids through orifices.

Values for the coefficient were determined for the more important conditions of engine service such as discharge under pressures up to 8000 pounds per square inch, at temperatures between 80° and 180° F. and into air compressed to pressures up to 1000 pounds per square inch. The results show that the coefficient ranges between 0.62 and 0.88 for the different test conditions between 1000 and 8000 pounds per square inch hydraulic pressure, at lower pressures the coefficient increases materially.

It is concluded that within the range of these tests and for hydraulic pressures above 1000 pounds per square inch the coefficient does not change materially with pressure or temperature; that it depends considerably upon the

liquid, decreases with increase in orifice size, and increases in the case of discharge into compressed air until the compressed-air pressure equals approximately three-tenths of the hydraulic pressure, beyond which pressure ratio it remains practically constant.

Report No. 230, Description and Laboratory Tests of a Roots Type Aircraft Engine Supercharger. By Marsden Ware. 13 pages, illustrations, quarto. Washington, Government Printing Office, 1926. Price, ten cents.

This report describes a Roots type aircraft engine supercharger and presents the results of some tests made with it at the Langley Field Laboratories of the Committee. The supercharger used in these tests was constructed largely of aluminum, weighed 88 pounds and was arranged to be operated from the rear of a standard aircraft engine at a speed of one and one-half engine crankshaft speed. The rotors of the supercharger were cycloidal in form and were 11 inches long and 9½ inches in diameter. The displacement of the supercharger was 0.51 cubic foot of air per revolution of the rotors.

The supercharger was tested in the laboratory, independently and in combination with a Liberty-12 aircraft engine, under simulated altitude pressure conditions in order to obtain information on its operation and performance. During an investigation of the influence on the operation of the engine of various types of air-duct connections between the supercharger and the engine, the supercharger was subjected to considerable rough treatment, which it endured very well, so that it seems apparent that the supercharger could well endure service handling. By the proper proportioning of the air-duct system, the engine would operate at all speeds as smoothly and free from vibration as the normal engine.

From these tests it seems evident that the Roots blower compares favorably with other compressor types used as aircraft engine superchargers and that it has several features that make it particularly attractive for such use.

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Recent Advances in Physical and Inorganic Chemistry, by Alfred W. Stewart, D.Sc. Fifth edition, 312 pages, illustrations, plates, 8vo. London, Longmans, Green and Company, Limited, 1926. Price, $6.50.

XX^{e} Salon International de Photographie, 1925. Société Française de Photographie. 15 pages, 48 plates, quarto. Paris, Braun and Company. Price, 36 francs.

Relay Handbook, prepared by the Relay Subcommittee, Electrical Apparatus Committee, Technical National Section, National Electric Light Association with the Coöperation of the Relay Subcommittee, Protective Devices Committee, American Institute of Electrical Engineers. 1001 pages, illustrations, 12mo. New York, National Electric Light Association, 1926. Price, $6, special price for ten copies or more.

Handbuch der Physik unter redaktioneller Mitwirkung, von R. Grammel, Stuttgart; F. Henning, Berlin; H. Konen, Bonn; H. Thirring, Wien; F. Trendelenburg, Berlin; W. Westphal, Berlin, herausgegeben von H. Geiger und Karl Scheel. Band X, Thermische Eigenschaften der Stoffe Redigiert

von F. Henning. 486 pages, illustrations, 8vo. Berlin, Julius Springer, 1926. Price, in paper, 35.40 marks; bound, 37.50 marks.

Technische Fortschrittsberichte. Fortschritte der chemischen Technologie in Einzeldarstellungen, herausgegeben von Prof. Dr. B. Rassow, Leipzig. Band X, Die photographisch-chemische Industrie von Dr. Ing. Friedrich Wentzel, Dresden. 363 pages, illustrations, 8vo. Dresden, Theodor Steinkopff, 1926. Price, in paper, 18.50 marks; bound, 20 marks.

Le Réalisme Einsteinien l'Optique et le Principe d'Invariance avec des Réflexions sur la concrète physique et son Mécanisme Fondamental, par Marcelin Dubroca, Professeur de Physique au Lycee Pasteur. 126 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie., 1926. Price, nine francs.

Nela Research Laboratory, Incandescent Lamp Department of General Electric Company. Abstract-Bulletin, Vol. 1, No. 4, December, 1925. 223 pages, illustrations, plates, portrait, 8vo. Cleveland, Ohio, Laboratory, 1925.

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American Telephone and Telegraph Company. Annual Report for the Year 1925. 34 pages, illustrations, 8vo. New York, Company, 1926.

U. S. Department of Agriculture, Bureau of Biological Survey. Our Migratory Wild Fowl and Present Conditions Affecting Their Abundance, by Edward W. Nelson, Chief, Bureau of Biological Survey. 17 pages, quarto. Washington, 1926.

Results of Magnetic Observations Made by the United States Coast and Geodetic Survey in 1924, by Daniel L. Hazard, Assistant Chief, Division of Terrestrial Magnetism. Special Publication, No. 116. 50 pages, 8vo. Washington, Government Printing Office, 1925. Price, ten cents.

Bell Telephone Laboratories, Inc. Reprints. B-181, Application of Statistics in Maintaining Quality of a Manufactured Product, by W. A. Shewhart. 3 pages, 8vo. B-182, Positive Rays in Thermionic Vacuum Tubes Containing Alkali-metal Vapors, by Herbert E. Ives. 23 pages, illustrations, 8vo. B-183, Electrical and Photo-electric Properties of Thin Films of Rubidium on Glass, by Herbert E. Ives and A. L. Johnsrud. 11 pages, illustrations, 8vo. B-184, Some Contemporary Advances in Physics, X, by Karl K. Darrow. 47 pages, 8vo. B-185, Theory of the Operation of the Howling Telephone, by Harvey Fletcher. 23 pages, illustrations, 8vo. B-186, Correction of Data for Errors of Measurement, by W. A. Shewhart. 16 pages, illustrations, 8vo. B-187, High-power Metallography, by Francis F. Lucas. 40 pages, illustrations, 8vo. B-188, The Luminous Properties of the Black-body, by Herbert E. Ives. 4 pages, 8vo. New York, Bell Telephone Laboratories, Inc., 1926.

National Advisory Committee for Aeronautics: Technical Notes, No. 232, The Lateral Failure of Spars, by Stevens Bromley and William H. Robinson, Jr. 18 pages, illustrations, photograph, quarto. Washington, Committee, 1926.

Madison Square Garden, One of New York's Architectural Landmarks. Reprinted by permission for The American Institute of Steel Construction from *The American Architect,* December 20, 1925. 23 pages, illustrations, quarto.

CURRENT TOPICS.

The Oil-electric Locomotive. (*Compressed Air Magazine.*)—A new development is the oil-electric locomotive—already in regular operation on four important eastern roads, ordered by five other lines in the East and Middle West, and engaging the serious attention of railroad executives throughout the country.

The oil-electric locomotive, as now established in actual service on American railroads, represents years of patient testing and experimentation by the engineering staffs of three collaborating organizations—the General Electric, American Locomotive and Ingersoll-Rand companies. All of the electrical equipment, specially designed for locomotive use, was developed by the General Electric Company. The trucks, underframe, platform and cab are products of the American Locomotive Company; and to the Ingersoll-Rand Company fell the task of designing an oil engine which, while compact enough for mounting in the limited space of a locomotive cab, would also be sturdy enough to withstand the extraordinary shocks and strains of railroad operation.

Briefly, the oil-electric locomotive is one in which an internal combustion engine, using low-cost fuel oil, drives an electric generator which furnishes power to electric motors geared to the axles of the driving wheels. Its advantages include more economical and speedier operation, greatly reduced maintenance cost, and the absence of noise and smoke. The Ingersoll-Rand oil engine used in the oil-electric locomotive is of the vertical, six-cylinder, four-cycle, single-acting, variable speed type having direct fuel injection. Cylinders, cylinder heads, and combustion chambers are completely water-jacketed. To start the engine, compressed air at approximately 200 pounds pressure is admitted to each cylinder in succession through mechanically operated starting valves. While in operation the engine drives a small air compressor which maintains pressure continuously in the starting reservoirs.

The generator is a 200-kw., 600-volt, direct-current, compound-wound, commutating pole unit, separately excited. The generator, together with its exciter, is specifically designed for this service and is direct-connected to the oil engine. The combined characteristics of generator and exciter are such as to produce a machine of practically constant output. The voltage of the generator is regulated by the current demand of the traction motors, so that, making due allowance for the generator losses, the product of this current and voltage is equal to the engine power. The kw. output of the generator varies with the output of the engine, and at any position of the throttle it is constant throughout the whole working range of the power plant. A 6-kw., 60-volt exciter is mounted on the same shaft with the

main generator and serves to excite the field windings of the main generator. A 32-volt storage battery is charged by this exciter through one of the field windings in series. The exciter and storage battery circuit is controlled automatically by a switch on the main throttle of the locomotive.

The locomotive is equipped with four motors mounted on the trucks and geared to the driving axles. These motors are of the series-wound, totally enclosed, commutating pole, split-frame type; the axle brackets and suspension lugs, being on the lower frame, render the motors readily accessible for inspection and repairs. The oil-electric locomotive may be operated with a fuel cost of 1/3 to 1/6 that of an equivalent steam locomotive. It makes possible the elimination of coaling plants, ash pits, turntables, roundhouses and hostling services—all of which are required for steam locomotives. Very little water is necessary, thus eliminating costly watering stations and troubles due to bad water conditions.

The new type of locomotive provides uniform, continuous torque at the wheel rims, which results in less wear on the tracks, and provides higher tractive effort at starting and slow speeds on lighter axle loads. The oil engine can be loaded full at all speeds, which aids in securing fuel economy. The electric transmission has the advantage over gear transmission in that it is self-shifting. The speed ratio between generator and the driving motors automatically adjusts itself to meet the demand of the service. This type of transmission also protects the oil engine from the strains and shocks to which it is subjected with a mechanical driving transmission between engine and driving wheel. It was demonstrated early in January of this year, that a 60-ton oil-electric locomotive can make a long run at an average fuel cost even lower than that of a Ford automobile. The locomotive was that now in operation on the Baltimore and Ohio Railroad, and the run, which was made unattached, was over a circuitous route of 733 miles from Erie, Penna., to New York City. The entire cost of fuel and lubricating oil for the trip was $8.75; or 1.2 cents per mile. L. E. P.

Modern Problems of Acoustics. E. WAETZMANN. (*Physik. Zeit.*, Dec. 8, 1925.)—In speaking of recent achievements in the field of acoustics the author mentions that he devised one apparatus by which mining in the earth was indicated at a distance of 50 metres under favorable conditions of the soil and a second by which aircraft could be heard to a distance of 25 km. He calls to attention the work done in America. "Through experiments on the course of sound waves, made with the help of models by E. Michel and through the study of absorption relations by W. F. Sabine, notable progress has been made so that we are by no means so helpless in the presence of problems of the acoustics of auditoriums as is often assumed." In determining the sensitiveness of the ear for different tones the method is to measure for each tone the least rate of supply of energy

that can be heard. The reciprocal of this quantity gives a measure of the sensitiveness, because the smaller the energy-rate or power the more sensitive the ear must be. Two curves connecting sensitiveness and frequency are given, one that of M. Wien, 1903, the other derived from the observations of our compatriots, Fletcher, Wegel, Laue, Swan, and Kranz. Throughout their entire lengths these never agree. For every tone the European curve shows a considerably higher value of the sensitiveness than does the American curve. In both curves the sensitiveness increases from a frequency of less than 100 per sec. up to about 2000 per sec. and then grows smaller for higher tones. Wien found the sensitiveness of the ear to be 1,000,000 times as great for a frequency of 2000 as for one of 100. The American results give a smaller ratio though of the same order of magnitude. For a source vibrating 2000 times per sec. the air particle at the ear of the hearer need only oscillate through an amplitude of 10^{-9} cm. to produce a sensation of sound. This distance is about 1/100 of the diameter of a molecule. The reason for the disparity of the two curves is not known. It may come in part, or, indeed, altogether, from the difference in sensitiveness between normal ears that has been experimentally established. For instance, Wegel and Fletcher found such differences to exist where the ratio of the sensitiveness was 1000.

For each tone there are two limiting rates of delivery of energy to the ear. The lower is the rate for the production of the faintest sensation of hearing. It is of this that the previous paragraph treats. The higher rate is that at which a sensation of pain is caused. Between these two rates there are of course many intermediate rates at which comfortable hearing is possible. To distinguish two notes of the same pitch but of different loudness there must be a difference of about 10 per cent. in their intensities, if they be of medium intensity. Thus for a given tone there is a definite number of intensities distinguishable between the two limiting rates mentioned above. If the tone have a frequency of 500 per sec., it cannot be distinguished from another unless the latter differ from it by one and a half vibrations per sec. Thus starting from the lowest tone at 20 vibrations per sec. and going up to 20,000, we should be able to hear and separate from one another a certain number of tones and, further, each of these tones we can hear at a definite number of different intensities. The total number of tones that can be told one from the other by reason of differences in pitch or in loudness, or in both, is about 300,000.

An interesting problem is being investigated in Breslau, that of the mutual effect of two vibrating bodies. Bjerknes lectured on this at the Toronto meeting of the B.A.A.S., using water as the medium surrounding the bodies. One set of experiments already published showed that there was mutual influence between a fixed telephone diaphragm and a rubber membrane attached to the end of the arm of a torsion balance. The former was set in vibration and the latter

was excited by picking up the waves originating at the diaphragm. So long as the periodicity of these was below the natural period of the membrane there was attraction of the latter toward the diaphragm. When the frequency was above that of the membrane, repulsion took place. When the waves had just the natural frequency of the membrane, neither attraction nor repulsion was found. The relation between force and frequency was discovered to depart from the curve predicted on the assumption that air is incompressible. A force of repulsion seems to be superimposed on the forces of attraction and repulsion. The experiments are being repeated with the substitution of a resonator for the membrane. The forces dealt with are of the order of 1/100 dyne per sq. cm. G. F. S.

Determination of Size of Colloidal Particles by Means of Alternating Current Fields. E. F. BURTON and MISS B. M. REID. (*Phil. Mag.*, Dec., 1925.)—In a colloidal solution the particles in suspension do not settle to the bottom as they might be expected to do, when they have a density greater than that of the surrounding liquid. It is the effect of the Brownian movement that contravenes the downward pull of the earth, if it is still permitted thus to speak in these days of the Einstein theory of gravitation. For any given material forming the suspended particles there is a certain size for which the velocity due to gravity is equal to that caused by the Brownian movement. "For all particles smaller than this the Brownian movement masks entirely the gravitational settling, and consequently the suspensions are permanent; for example, there exists at the present time in the Royal Institution, London, samples of gold colloidal solutions in water prepared some seventy-five years ago by Faraday." The aim of this paper is to present a method by which the motion of settling can be segregated and measured. This is accomplished by applying a vertical electrical field to the colloidal solution, whose particles have electrical charges. When this field is so directed as to exert a downward force on the particles, it is augmented by the pull of gravity on them and a particle in a given time moves downward through a certain distance as a result of the joint action of the two forces against the opposition of the Brownian movement. Let the electrical field be reversed in direction and applied for the same length of time as before. The electrical force now opposes the force of gravity and a particle will move upward, provided the former is the stronger. The Brownian movement interferes just as before. "The difference between the up-and-down motion will then be due to the settling caused by gravity, and to this motion Stokes' law can be applied." From this the radius of the particle can be calculated. It should be emphasized that the applied field must be sufficiently strong to impart a velocity to the particles much greater than that which they derive from either gravity or the Brownian movement.

A series of copper sols with particles of different sizes was

prepared. One such colloidal solution was introduced into the lower part of a U-tube. Above it stood water of the same specific conductivity as the solution. A sharp boundary separated the two liquids. The electrical field was supplied by an 80-volt storage battery joined to electrodes dipping into the water. This field was reversed every 90 seconds automatically and it was applied for seven hours in an experiment. The settling of the boundary during this interval ranged from .225 to .325 cm. and the corresponding radii of the particles were computed to be 7.14×10^{-6} and 8.60×10^{-6} cm. When somewhat larger particles were used in the colloidal solution it was found that coagulation soon took place "showing that the size of the particles had increased to such an extent that the Brownian movement no longer masked the effect of gravity." G. F. S.

Coal-dust Explosions.—The use of powdered coal is increasing. The hazards involved in it having proved serious, they have been extensively investigated by the U. S. Bureau of Mines. In a recently issued Bulletin (242) of that bureau a summary is given of both experiments, observations and investigations of accidents. It has long been recognized that combustible dusts of all types are capable of causing violent explosions, even aluminum dust having this property. The Bureau of Mines discovered some years ago that starch dust in admixture with air is a most powerful explosive.

Powdered coal offers considerable advantage as fuel. It has been found especially applicable in plants that have been originally established to operate with natural gas, when the supply of this has declined, since the furnaces are not adapted to the usual form of coal. The application of powdered coal is useful when a very high temperature is required. As the supply of natural gas may be expected to decline, the use of powdered fuel may be expected to increase and the fire and explosion hazards will become more and more important. The average fineness is such that 93 per cent. will pass through a hundred-mesh screen and 71 per cent. through one of 200 mesh. Coal which is retained on a 20-mesh screen is not a cause of explosion. Of course, the coal even of the most extreme fineness is not explosive in bulk, but only when thoroughly mixed with air. On the other hand, such coal is liable to spontaneous combustion. The liability to explosion will depend not merely on the fineness of the grains, but upon the percentage of inert matter. The amount of incombustible matter in the material that will render it non-explosive is directly proportional to the ratio of the volatile matter to the total combustible, and is expressed by dividing the per cent. of volatile matter by the same datum plus the fixed carbon, but the rule will not apply to a sample in which the ash of composition plus the inert matter equals 90 per cent.

The hazards in the use of powdered fuel are by no means limited to the use in furnaces. Accumulations of unused material in bins and on ledges of buildings, dust arising in the loading, unloading and other transfer of the fuel, set up dangerous conditions and many instances

of serious accidents from such causes are detailed in the report. Even coal not specially powdered, such as "run-of-mine" or screenings, may cause disaster. In a Pittsburgh plant a short circuit formed by the accumulation of moist coal dust around the terminals of a back-connected electric switch caused the blowing out of the main fuse of installation with such violence that the fuse cartridges were shattered and the main panel partly wrecked. Fortunately the accident occurred at a time when the works were shut down and no dust particles were distributed in the air. Open lights in dusty places are a common source of accidents. It must be borne in mind that an unbroken electric light bulb may cause trouble if it is covered with dust. A workman, cleaning a bin, might leave a lamp burning that in time would be covered by the powdered fuel filled into the bin. This lamp would bring about spontaneous combustion.

In the summary of the data given in the report, emphasis is properly laid upon the importance of workmen using care and attention in all operations about the plant. The most perfect installation cannot make it fully "fool-proof." It is especially important that all persons employed about a plant using pulverized coal should be fully aware of the explosiveness of any combustible dust mixed with air. The danger is greater because the accumulation of dust in corners and on ledges is not likely to attract attention. A leak of gas is usually soon noticed, but powdered fuel is inodorous. Many rules for operation of plants using powdered fuel are given in the report, which is well worth the attention of all persons interested. H. L.

Bats As Insect Exterminators.—Attention has been called lately to this subject by a book by Dr. Charles A. R. Campbell, of San Antonio, Texas, entitled "Bats, Mosquitoes and Dollars"; also by a Bulletin of the U. S. Department of Agriculture (1395, March, 1926). Doctor Campbell is an enthusiastic advocate of the value of bats as mosquito exterminators and also as producers of guano. The latter phase is not important here, but the destruction of mosquitoes is a matter that interests every one. Doctor Campbell claims that by the establishment of bat-roosts, great numbers of animals may be congregated and the malarial mosquito practically exterminated. He has successfully established a large roost in his locality, but it appears from the investigations of the experts of the U. S. Department of Agriculture, summarized by E. W. Nelson, Chief of the Bureau of Biological Survey, that such roosts have been successful only in this case. There are known about 260 species and sub-species of bats in North America, the particular one that seems to be most responsible in the reports for its mosquito-destroying power is the Mexican "free-tailed bat" (*Tadarida mexicana*), the range of which is in general restricted to the arid and semi-arid regions from Texas to California, extending into the warmer areas of Mexico. Bats are stated to be not at all prolific, usually bringing forth only one young per mother each year.

Doctor Campbell's book was reviewed in this JOURNAL (**200**, p. 697, 1925), credit being given for the scientific manner in which he has investigated the subject, but it was pointed out that any effort at increasing the number of bats would be objected to by most persons, and that it is practically impossible to eradicate the curious superstitions and fears concerning these animals. There is little doubt that their forms and night-flying habits are largely responsible for the dread of them. Most species of bats are either insect eaters or fruit eaters, but some of the tropical forms are blood-sucking, and there is always a liability for an animal of such a type to resort to blood-sucking when the usual food is scarce.

The U. S. Bulletin summarizes the investigations by the experts of the Bureau of Agriculture as follows:

North American bats destroy a large number of insects but have not been observed to exterminate any species. In estimating their powers in this respect it must be borne in mind that they are almost exclusively night-flying animals.

Attempts to colonize bats in large roosts have so far been successful in one case only.

Mosquitoes have been found in abundance in and about bat-caves and in the one case in which a large bat-roost has been established, mosquitoes have not been appreciably diminished. The hope of extermination of these insect pests by means of bats seems entirely unfounded. H. L.

The Application of Michelson's Method of Measuring Stellar Dimensions to the Measurement of Small Particles. U. GERHARDT. (*Zeit. f. Phys.*, **35**, Nos. 8 and 9, 1926.)—In Michelson's method two parallel slits are mounted in front of the objective of a telescope in a plane perpendicular to the axis of the instrument. If a double star is examined each of the component stars forms a series of interference fringes. By moving one of the slits parallel to itself these two sets of fringes may be made to overlap so that the darkest parts of one fall upon the brightest parts of the other. Thus the interference patterns are made to disappear. When this is the case, the angular separation of the two stars can be simply computed from the distance separating the slits and the wave-length of the light used. For a single star the diameter can be obtained by the same process and by a formula of calculation differing only slightly from the one applicable to double stars. Readers will, perhaps, recall the interest aroused several years ago by the announcement of the diameter of Betelgeuse determined by this method.

Michelson himself suggested that a similar method could be used to enhance the resolving power of a microscope. It seems that no one had actually made the application previous to the work reported in the present paper. A description of the modified apparatus and of the method of manipulation is given. "It is further shown that, just as was true with the telescope, so is it also the case with the microscope

that the resolving power of an objective is doubled by the interference observations in comparison with unaided observations." We must, however, keep in mind that the use of mirrors extending laterally far beyond the telescopic objective greatly increased the resolving power of the instrument. In the case of the microscope, theory indicates that a particle of a diameter of .000106 mm. could be measured with an immersion system of numerical aperture 1.3, with light of wavelength .00055 mm. The smallest diameter of a particle actually measured was .00024 mm. G. F. S.

Registration at Berlin of the La Courtine Sound Wave. F. RITTER. (*Zeit. f. Tech. Phys.*, No. 3, 1926.)—On two different days in May, 1924, about 10,000 kg. of explosives were set off at La Courtine, near the geographical centre of France. As notice was given of these events observations of the sound waves were made at several places. At the Chemisch-Technische Reichsanstalt a mirror was arranged to move with the yielding of a window-pane and its motion was recorded photographically. The distance from the seat of the explosion to the place of observation is 1162 km. To traverse this distance 1 h. 3 min. 21 sec. was required on the first day and 1 h. 1 min. 10.4 sec. on the second. Both traces showed that a rarefaction arrived first. The periods of the two waves were 1.4 and 1.3 sec. and their respective pressure amplitudes ±.0041 g./cm.^{2} and ±.0007 g./cm.^{2}. There was a third explosion two days after the second, when 4875 kg. of melinite were exploded, but the traces of this were not clear, as a strong wind was blowing. G. F. S.

Sulphur in Coal.—Sulphur is found in almost all fuels and is especially noticeable in coal. A study of the subject has been published in the *West Virginia University Bulletin* (1925, **2**, 31) contributed by Messrs. Fraser and Yancey. The former is Professor of Mining in the University, the latter Associate Chemist, U. S. Bureau of Mines. As all workers in fuel analysis know, the percentage of sulphur has a wide range. Some of the far western American high-ash coals contain less than 0.3 per cent., while Brazilian coals may carry 12 per cent. It is an objectionable ingredient in all uses to which fuel is put. The conspicuous compound in coal is pyrites in the form of marcasite. Calvert in 1871 was the first to recognize the existence of sulphates, and to devise a method for determination. Experience has shown that sulphates are not present in large amount in freshly mined coal, except in some far western samples that contain calcium sulphate. Sulphur in association with hydrocarbons, the so-called "organic sulphur" is apparently an invariable constituent, often in notable amount, and constitutes one of the most serious impurities, for in the manufacture of tars and gases by distillation this sulphur appears in forms that are very difficult to remove. Benzene, one of the most important "crudes" in tar technology, often contains thiophene in which sulphur is in the ring with carbon atoms. Powell and Parr

in 1919 showed that two forms of organic sulphur usually exist in coal. Iron sulphide occurs in different forms. Examination of sections under the microscope shows often minute particles of pyrite or marcasite.

Fraser and Yancey give numerous analyses of coals to show the respective proportions of pyrite and organic sulphur and also tables showing material reduction of sulphur by methods of washing. The paper concludes with a discussion of the relation of sulphur to the manufacture of pig iron. H. L.

THE number of February 27, 1926, of *Revue Scientific*, contains the article on "Atomic Radiation in Magnetic Fields" read by Prof. P. Zeeman at the Centenary of The Franklin Institute. The translation into French was made by A. Boutaric, of the University of Dijon. G. F. S.

Malaria Mosquitoes Controlled by Airplane Dusting. (U. S. Dept. of Agriculture.)—Considerable success has attended the experiments of the United States Department of Agriculture in the use of the airplane as a means of distributing poison dust over both treeless and wooded swampy areas for control of malaria mosquitoes. In the final tests more than 99 per cent. of the larvæ in the area treated were destroyed with one application. Paris green was the larvicide used in all the experiments. The procedure used in carrying out the tests is described in Department Circular 367, just issued by the department.

In developing the method of handling the planes so as to distribute the dust properly and in determining the quantity of Paris green to use, flights were made first over open fields, then over dry woods, and finally over various types of mosquito-breeding swamp and lake areas.

With an experienced pilot, and when careful attention was given to the spread of the dust, no special difficulty was encountered in distributing it over the treeless parts of the lakes. Furthermore, from a single experience in treating rice fields, this type of breeding place appears to be particularly well adapted to control by airplane dusting, because of the absence of trees and other obstructions which interfere with close flying. Even in such places as the heavily wooded areas where the water was protected by dense overhead foliage and where the planes had to be flown high enough from the ground to clear the tallest trees, the dust was found to have penetrated the thick growth and to have reached the water in sufficient quantities to destroy the larvæ.

The quantity of Paris green used in the experiments varied from about one-twentieth of a pound to several pounds per acre. Because of the small amount of poison required to kill the larvæ the Paris green was mixed with an inert dust of some sort, finely ground silica earth being the carrier used in most cases.

In each test a series of pans containing known numbers of larvæ were distributed over the area to be dusted. Counting the living larvæ after dusting furnished a check on the effectiveness of the application.

Two final-tests gave particularly clear-cut results, and for this reason were of special interest in showing the possibilities of this method of control in breeding areas of the type represented, the lakes overgrown with aquatic vegetation and having an abundance of Anopheles larvæ well distributed throughout. In the first of these a larval reduction of 88 per cent. occurred as a result of the treatment, and in the second more than 99 per cent. were killed. The only larvæ remaining in the second instance were a few of the smallest size, found in one small spot.

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